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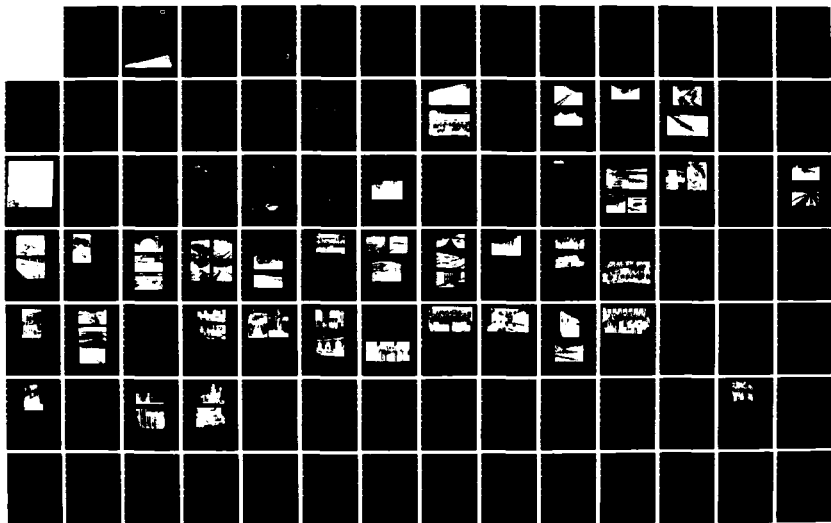
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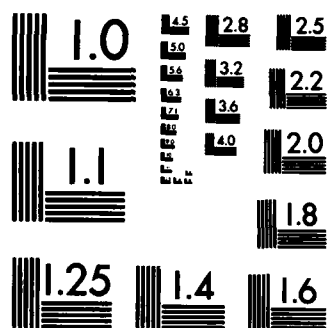
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# Special Report 85-9

June 1985



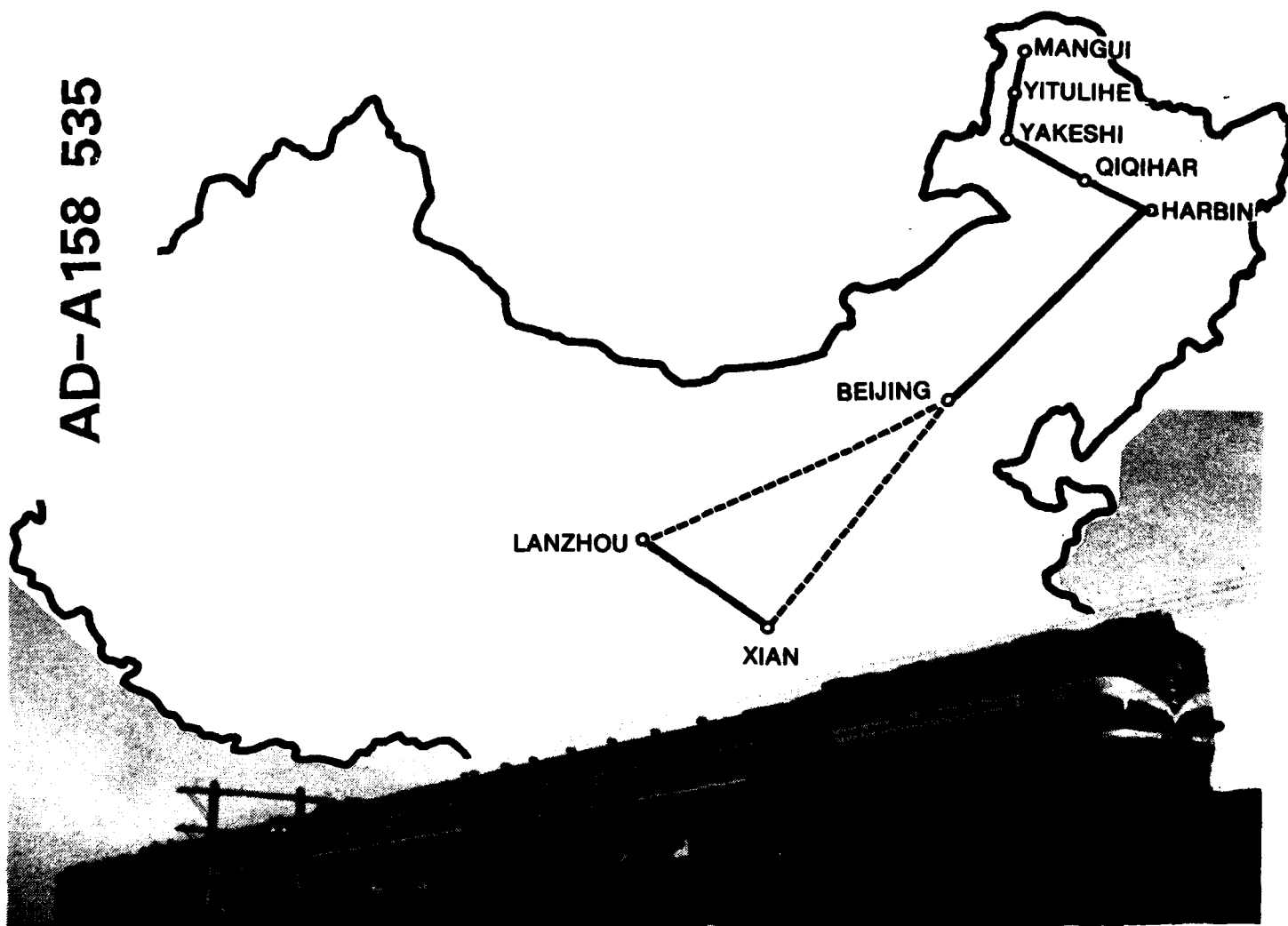
US Army Corps  
of Engineers

Cold Regions Research &  
Engineering Laboratory

## *U.S. permafrost delegation visit to the People's Republic of China, 15-31 July 1984*

Jerry Brown

AD-A158 535



Prepared in cooperation with  
COMMITTEE ON PERMAFROST  
POLAR RESEARCH BOARD  
NATIONAL RESEARCH COUNCIL  
WASHINGTON, D.C.

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Christopher E. Heuer, Exxon Production Research Company  
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Raymond A. Kreig, R.A. Kreig and Associates  
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Troy L. Pewe, Ex Officio, Arizona State University  
Stuart E. Rawlinson, Liaison, Alaska Division of Geological and Geophysical Surveys

***Cover: Map of China showing main locations  
visited by delegation. Solid line indi-  
cates route covered by rail. The spe-  
cial four-car train, provided by the  
Harbin Railway Administration, was  
used between Harbin and Mangui.***



Special Report 85-9

U.S. PERMAFROST DELEGATION VISIT TO THE  
PEOPLE'S REPUBLIC OF CHINA  
15-31 JULY 1984

Jerry Brown

June 1985

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Prepared in cooperation with

Committee on Permafrost, Polar Research Board  
National Research Council, Washington, D.C.

by

Cold Regions Research and Engineering Laboratory  
Hanover, New Hampshire

## PREFACE

This visit was made possible by an invitation from the Chinese Ministry of Railways. Li Yusheng, leader of a Chinese delegation to the U.S. in 1983, and at the time, vice president of the Academy of Railway Sciences, was instrumental in arranging the invitation. The Foreign Affairs Bureau of the Ministry of Railways arranged the many details of the trip. Zhou Hongye, vice president of the Academy of Railway Sciences, and Zhao Yuehai, interpreter from the Ministry, accompanied the delegation throughout its visit and facilitated many aspects of the exchange. Numerous institutes and administrative organizations were involved in specific visits. These groups are mentioned throughout the report, and their continuing efforts to make our visits productive and memorable are collectively acknowledged. Particular appreciation goes to the directors and staff of the Academia Sinica's Institute of Glaciology and Cryopedology for all its efforts during the short visit in Lanzhou.

The delegation was organized by Jerry Brown as chairman, Committee on Permafrost, and Troy L. Péwé, chairman, U.S. Organizing Committee for the Fourth International Conference on Permafrost, committees of the Polar Research Board, National Research Council.

The report was compiled, edited, and rewritten by Jerry Brown. However, all members of the delegation contributed to the initial writing and subsequent revisions. The following individuals prepared drafts or contributed to the major sections:

Permafrost and Route Conditions: Troy L. Péwé, Raymond A. Kreig, Richard D. Reger, and Stuart E. Rawlinson. Engineering Practices and Institute Visits: Richard L. Berg, Ted S. Vinson, Michael C. Metz, David C. Esch, Robert E. Smith, and Victor Manikian. Oscar J. Ferrians, Jr., Larry R. Sweet, Gunter E. Weller, and George Gryc provided helpful editorial suggestions and revisions. Raymond A. Kreig and Stuart E. Rawlinson provided many helpful changes to the final draft.

Arrangements for the trip were greatly facilitated by the assistance of the National Academy of Sciences Committee on Scholarly Exchanges with the People's Republic of China and particularly Alice Bishop, Amy Wilson, and Robert Geyer. Louis DeGoes provided assistance in arrangements prior to the trip.

CRREL's participation was provided by several Corps of Engineers projects, including Environmental Constraints on Frozen Terrain.

Eleanor Huke prepared the illustrations and Edmund Wright and Maria Bergstad edited the report.

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## SUMMARY

A U.S. delegation of 15 scientists and engineers representing federal and state agencies, industry, and universities specializing in problems of seasonally and perennially frozen ground visited China during the period 15-31 July, 1984. The trip was organized by the Ministry of Railways and was co-hosted by the Academia Sinica's Institute of Glaciology and Cryopedology in Lanzhou. The 16-day visit was in return for a U.S.-hosted visit of a Chinese delegation to Alaska and the West Coast in July 1983 as part of the Fourth International Conference on Permafrost. The U.S. Committee on Permafrost of the National Research Council organized the U.S. participation. Ten of the U.S. delegates were hosted by the Ministry of Railways while in China. The other five delegates were responsible for paying their own costs.

The visit consisted of two segments: a train trip through the western permafrost region of northeast China and technical sessions in Lanzhou. Both visits were requested by the U.S. organizers upon receipt of the official invitation from the Ministry of Railways in January 1984. The objectives of these visits were to (1) ensure field trips to view permafrost conditions and construction practices in a region comparable to interior Alaska; (2) meet with organizations responsible for frozen ground research, design, and construction; and (3) exchange detailed technical information with two major frozen ground institutes in Lanzhou. The visit followed an earlier visit by a Canadian permafrost delegation in 1977, and several visits by Péwé and Brown in 1980, 1981, and 1982.

The train trip to northeast China began at Harbin. The train proceeded to Yakeshi on the Pin Zhou Railway, then went to the end of the Yalin Line at Manguí in northern Inner Mongolia and returned by the same route to Qiqihar. A total of 1984 km was covered on a private, four-car train that passed through 235 railway stations and four subdivisions of the Harbin Railway Administration. The train stopped en route at six permafrost locations. The delegation spent a total of 10 days on trains that covered more than 5000 km (round trip) from Beijing. The train trip through Heilongjiang Province and Inner Mongolia was organized by the Harbin

Railway Administration, which has more than 230,000 employees and 10,000 km of track.

Exchanges with the following institutes and laboratories took place in northeast China:

- Heilongjiang Provincial Hydraulic Scientific Research Institute and the Wanjia Frozen Soil Field Test Station, Harbin.
- Heilongjiang Provincial Low-Temperature Construction Science Research Institute, Harbin.
- Yakeshi Forest Survey and Design Institute.
- Yitulihe Frozen Ground Observation Station.
- Qiqihar Research Institute of Science and Technology of the Harbin Railway Administration and its Low-Temperature Laboratory.

The visit to the Wanjia Frozen Soil Field Test Station illustrated field testing of piles and foundations subjected to deep seasonal frost penetration and heave. A well-illustrated video tape and slide presentation supplemented the field observations. While in Harbin, the U.S. delegates presented several summary talks on frost heave, in situ measurements, and pile foundations at the Low-Temperature Construction Science Research Institute.

A one-day technical exchange took place at Yakeshi with Chinese and U.S. groups each presenting four talks. The Chinese covered permafrost distribution and mapping, and the design, construction, and performance of railbeds, culverts, bridges, and building foundations. They presented results of their field observations and successes and failures of structures associated with frost heave and permafrost degradation.

Two technical exchanges took place with the Qiqihar railway representatives, one on the train and one at the Low-Temperature Laboratory in Qiqihar. A series of questions and answers was exchanged between the U.S. and Chinese specialists on the train. In the final session in Qiqihar, the U.S. summarized on-going and future frozen-ground research in federal and State of Alaska agencies and industry. The Chinese concluded with a tour of the Low-Temperature Laboratory's large coldroom and material testing facility and a slide show recapping the train trip, including sites and conditions not visited due to time restrictions. A photo album and a comprehensive report on past field investigations and design and construc-



tion practices were provided to each delegate. The report is being translated by the U.S. and will be published for wider distribution.

The trip in northeast China provided a number of new insights into recent Chinese frozen-ground investigations. Our most recent contacts have been through papers and reviews presented and published in conjunction with the Fourth International Conference on Permafrost. However, the actual experience of visiting institutes and field sites, and participating in discussions with large numbers of Chinese specialists, provided the opportunity to refine our own understanding of current engineering practices and their limitations, and of the distribution of permafrost in northeast China. Clearly the design and construction of railways over permafrost is well advanced in China. Problems related to railway winter drainage, reduction in thaw settlement, damage to culverts, and frost heave have been experienced and in many cases resolved. Large labor resources allow excellent maintenance of the railbed. Much of the northeastern railway system serves forestry needs and specialized institutes, and field stations have been established to obtain design data. In the past decade new approaches have been made to foundation design. Ventilated slab and pile foundations are being used for dwellings and other structures. However, experience in these areas appeared to be limited.

The distribution of permafrost in China was clarified by the visit. Much of the extreme northeastern part of Inner Mongolia is underlain by permafrost and should be considered to be in the northern part of the discontinuous permafrost zone. We observed ground-temperature observation wells in disturbed areas, and generalized maps of ground temperatures were provided. Detailed maps of permafrost distribution were not available. The U.S. delegation had with them several enhanced Landsat images for parts of the routes, which proved useful in discussions and for field checking. The Chinese were most interested in these images. Approximately 100 Chinese aerial photographs of the Mangui area were examined.

After a visit to Xian, the delegation went to Lanzhou, where it was hosted by the Academia Sinica's Institute of Glaciology and Cryopedology and the Northwest Institute of the Chinese Academy of Railway Sciences (CARS). A half day was spent in each institute in briefings and visits of the facilities. Several of the delegates had previously visited the insti-

tutes and were able to note changes. The second and final day was devoted to two concurrent sessions on general geocryology and engineering geocryology. All 15 U.S. delegates presented talks, and there were five Chinese presentations. Approximately 100 Chinese attended. A number of discussions took place on the topics of frost heave, remote sensing, and piles and foundations. These intensive discussions resolved many questions regarding Chinese engineering geocryology, particularly on foundation design and frost heave research.

Details of the 16-day visit are presented in the following comprehensive report based on input from the individual delegates. Potential topics for future exchanges were discussed with both CARS and the Lanzhou Institute. All institutes and administrative offices visited were enthusiastic about future exchanges. The frozen ground activities in both the U.S. and China transcend traditional organizational responsibilities in agencies and academies. In China, major interests are in the Academia Sinica, the Ministry of Railways, and several provincial administrations. In the U.S., there is no single agency, institution, or constituency that has responsibility or the resources to support an overall agreement. Recently, coordination and organization of the exchange have been by the U.S. Committee on Permafrost of the National Research Council. It has sought broad scientific and engineering participation, and this multidisciplinary approach needs to be preserved.

In Beijing, a courtesy visit was made to the Academia Sinica's Foreign Affairs Bureau, and a visit by several delegates to its Institute of Remote Sensing Applications was arranged. One delegate lectured at the Geological Institute of the Academia Sinica. Another delegate with particular interest in terrain and route analysis remained for several days to lecture and visit the Ministry of Railways Special Design Institute.

## INTRODUCTION

A delegation of 15 U.S. scientists and engineers representing federal and state agencies, industry, and universities specializing in problems of seasonally and perennially frozen ground visited China during the period 15-31 July, 1984 (Table 1). The 16-day visit was in return for a U.S.-hosted visit of a Chinese delegation to Alaska and the West Coast in July 1983 as part of the Fourth International Conference on Permafrost (see Appendix C). The trip was organized by the Ministry of Railways and was co-hosted by the Academia Sinica's Institute of Glaciology and Cryopedology in Lanzhou. The U.S. Committee on Permafrost of the National Research Council organized the U.S. participation. Table 2 shows the detailed itinerary for the 16-day visit. The route partly followed that taken by a Canadian frozen-ground delegation in 1977, which went to both Mangui and Chintao (Jintao).

Contact with Chinese permafrost specialists was first established by Canadians in 1975. In 1978 we met personnel of Academia Sinica and the Ministry of Railways at the Third International Conference on Permafrost in Edmonton, Canada. Visits to the People's Republic of China by Péwé in 1980 and 1982 (Péwé, 1980) and Brown in 1981 (Brown and Yen, 1982) helped set the stage for the 1983 visit to the U.S. by a Chinese delegation. Several review papers by Chinese engineers and scientists provided valuable background on permafrost distribution and construction problems and solutions (Li et al., 1983; Zhou and Guo, 1983).

Although our trip was officially hosted by the Ministry of Railways and its Foreign Affairs Bureau, the Chinese Academy of Railway Sciences (CARS) and its vice-president Zhou Hongye were our main contacts. Zhou accompanied us on the entire trip.

The Ministry of Railways is the largest civilian ministry in China, with over 2.6 million employees. Its Academy of Railway Sciences (CARS) has a staff of 3800, 3000 of whom are in Beijing. The remainder are at the

Table 1. United States Permafrost Delegation

---

Leader: Jerry Brown, chairman, Committee on Permafrost of the National Research Council, and Cold Regions Research and Engineering Laboratory

Deputy Leader: Troy L. Péwé, vice-president, International Permafrost Association, and Arizona State University

Members:

Richard L. Berg, chairman, Committee on Freezing and Thawing of Soil-Water Systems (ASCE), and Cold Regions Research and Engineering Laboratory

David C. Esch, chairman, Committee on Frost Action (TRB), and Alaska Department of Transportation & Public Facilities, Fairbanks

Oscar J. Ferrians, Jr., U.S. Geological Survey, Menlo Park

George Gryc, U.S. Geological Survey, Menlo Park

Raymond A. Kreig, R.A. Kreig & Associates, Inc., Anchorage

Victor Manikian, ARCO Alaska, Inc., Anchorage

Michael C. Metz, GeoTec Services, Inc., Golden

Stuart E. Rawlinson, Alaska Division of Geological & Geophysical Surveys, Fairbanks

Richard D. Reger, Alaska Division of Geological & Geophysical Surveys, Fairbanks

Robert E. Smith, ARCO Oil and Gas Co., Dallas

Larry R. Sweet, Alaska Department of Transportation & Public Facilities, Fairbanks

Ted Vinson, Oregon State University, Corvallis

Gunter Weller, University of Alaska, Fairbanks

---

Northwest and Southwest Institutes. The Southwest Institute specializes in mountain bridges and tunnels and hydraulics. The Northwest Institute in Lanzhou was first visited by foreigners in 1981 (Brown and Yen, 1982).

CARS has eight institutes in Beijing: (1) Construction, (2) Materials and Chemicals, (3) Locomotives, (4) Transportation, (5) Railway Standards, (6) Computer Applications, (7) Information, and (8) Signals and Communication. The Construction Institute has the largest staff, with 280. Some 30 to 35

Table 2. Daily Itinerary

- 
- |         |  |
|---------|--|
| 15 July | Delegation arrived in Beijing on JAL 481 from Tokyo. Met by Ministry of Railways delegation and taken to Chien Men Hotel. Briefing by Chen Jiyan of the Foreign Affairs Bureau of Ministry and discussions with Doug McNeal, U.S. Embassy, in the evening at hotel.                                |
| 16 July | Visits to Great Wall and Ming tombs by Ministry bus. Brown visited Embassy. Péwé lectured at Geological Institute. Ministry hosted banquet at Beijing Duck Restaurant.   |
| 17 July | Visits to Temple of Azure Clouds, Temple of Sleeping Buddha, Summer Palace, and Forbidden City. Brown and Péwé visited the Foreign Affairs Bureau of the Academia Sinica in afternoon. Delegation departed for Harbin at 8:07 p.m. on Train 39.  |
| 18 July | Arrived Harbin 1:30 p.m. and met by Harbin Railway Administration. Toured city and visited Children's Park, riverside railway amusement park, and boat ride on Songhua River. Banquet in Swan Hotel hosted by the Harbin Railway Administration.   |
| 19 July | Morning visit to Wanjia Frozen Soil Field Test Station. Afternoon visit to Hydraulic Scientific Research Institute's laboratories and technical exchange at Low-Temperature Construction Science Research Institute. Banquet at the Institute. Departed for Yakeshi on special train at 10:22 p.m. |
| 20 July | En route to Yakeshi along Pin Zhou railway. Arrived at 6:40 p.m. Reception and dinner at the Yakeshi Guest House.  |
| 21 July | Day-long technical exchanges at Guest House. Banquet hosted by Yakeshi Institute. Departed by special train for Mangui at 8 p.m.   |
| 22 July | Stops along Yalin Line to Mangui. Arrived at Mangui for short visit at 10 a.m. and returned to Yitulihe. Visited Yitulihe Frozen Ground Observation Station. Departed by special train for Qiqihar.  |
| 23 July | En route to Qiqihar. Delegation met to organize report. Met with Chinese to exchange information on specific questions. Banquet on train. Evening arrival in Qiqihar and overnight at Hongbin Hotel.   |
| 24 July | Morning visit to Low-Temperature Laboratory of Qiqihar Research Institute of Science and Technology. Technical exchange and summary of visit to northeast China. Afternoon visits to Zhalong Nature Preserve, new railway station, city port, and river front. Overnight at Hongbin Hotel.         |
| 25 July | Departed for Beijing at 8:13 a.m. on express train.  |

Table 2 (cont'd). Daily itinerary.

- 26 July Arrived Beijing at 11 a.m. and went directly to airport. Departed at 2 p.m., and arrived Xian 4 p.m.; visited Big Wild Goose Pagoda. Banquet by the Xian Railway Administration at Xian Hotel.
- 27 July Visited terra cotta warriors, Hua Quing Hot Springs, and jade factory. Departed by train for Lanzhou at 2:30 p.m.
- 28 July Arrived Lanzhou at 6 a.m. and transferred to Ning Wu Zhuang Hotel. Visits and briefings at Institute of Glaciology and Cryopedology (Academia Sinica) in morning and Northwest Institute (Ministry of Railways) in afternoon. Banquet at the Lanzhou Institute dining hall.
- 29 July Concurrent technical sessions at Lanzhou Institute on general geocryology and engineering geocryology. Banquet hosted by Northwest Institute.
- 30 July Brown and Weller met with Academia Sinica's Institute of Atmospheric Sciences. Departed for Lanzhou Airport at 9:30 a.m. Returned to Beijing.
- 31 July Departure from Beijing. Brown and Kreig visited Academia Sinica's Institute of Remote Sensing Applications prior to departure. Kreig remained to visit Ministry of Railways design and survey groups.
- 

master's degrees and 1 to 3 Ph.D. degrees are granted annually at CARS. There are three main subdivisions: (1) Administrative and Finance, (2) Technical Information, and (3) Research and Continuing Education. Zhou Hongye has recently become vice-president of the Research group, replacing Li Yusheng who is now vice-president of the Ministry's publishing house. Li led the Chinese permafrost delegations to Canada in 1975 and 1978 and to Alaska in 1983.

The visit consisted of two segments: a train trip through the western permafrost region of northeast China and technical sessions in Lanzhou. Both visits were requested by the U.S. organizers upon receipt of the official invitation from the Ministry of Railways in January 1984. The objectives of these visits were (1) to ensure field trips to view permafrost conditions and construction practices in a region comparable to interior Alaska; (2) to meet with organizations responsible for frozen-ground research, design, and construction; and (3) to exchange detailed technical

Table 3. Visits with Chinese Institutions - 15-31 July, 1984

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NORTHEAST CHINA

Heilongjiang Provincial Institutes  
Low-Temperature Construction Science Research Institute  
Hydraulic Scientific Research Institute  
Wanjia Frozen Soil Field Test Station  
Harbin Railway Administration  
Qiqihar Research Institute of Science and Technology  
Low-Temperature Laboratory  
Yitulihe Frozen Ground Observation Station  
Yakeshi Forest Survey and Design Institute

LANZHOU

Institute of Glaciology and Cryopedology, Academia Sinica  
Institute of Atmospheric Sciences, Academia Sinica  
Northwest Institute, Chinese Academy of Railway Sciences

BEIJING

Institute of Remote Sensing Applications, Academia Sinica  
Institute of Geology, Academia Sinica  
Special Design Institute, Ministry of Railways  
Geography Department, Peking University

---

information with the two major frozen-ground institutes in Lanzhou. Table 3 lists the institutions visited during the trip.

The special train trip to northeast China began at Harbin. The train proceeded to Yakeshi on the main Pin Zhou trunk line, then went to the end of the Yalin Line at Mangui in northern Inner Mongolia and returned by the same route to Qiqihar (Fig. 1). A total of 1984 km was covered on a private, four-car train passing through 235 railway stations and four subdivisions of the Harbin Railway Administration. The train stopped en route at six permafrost locations. The train had a rear observation and conference car, which greatly aided the delegation in observing and photographing the terrain and the condition of the railway tracks and structures. A total of 10 days was spent on trains that covered more than 5000 km round-trip from Beijing. The train trip through Heilongjiang Province and Inner Mongolia was organized by the Harbin Railway Administration.

The trip in northeast China provided a number of new insights into recent Chinese frozen-ground investigations. Our most recent contacts have been through papers and reviews presented and published in conjunction with

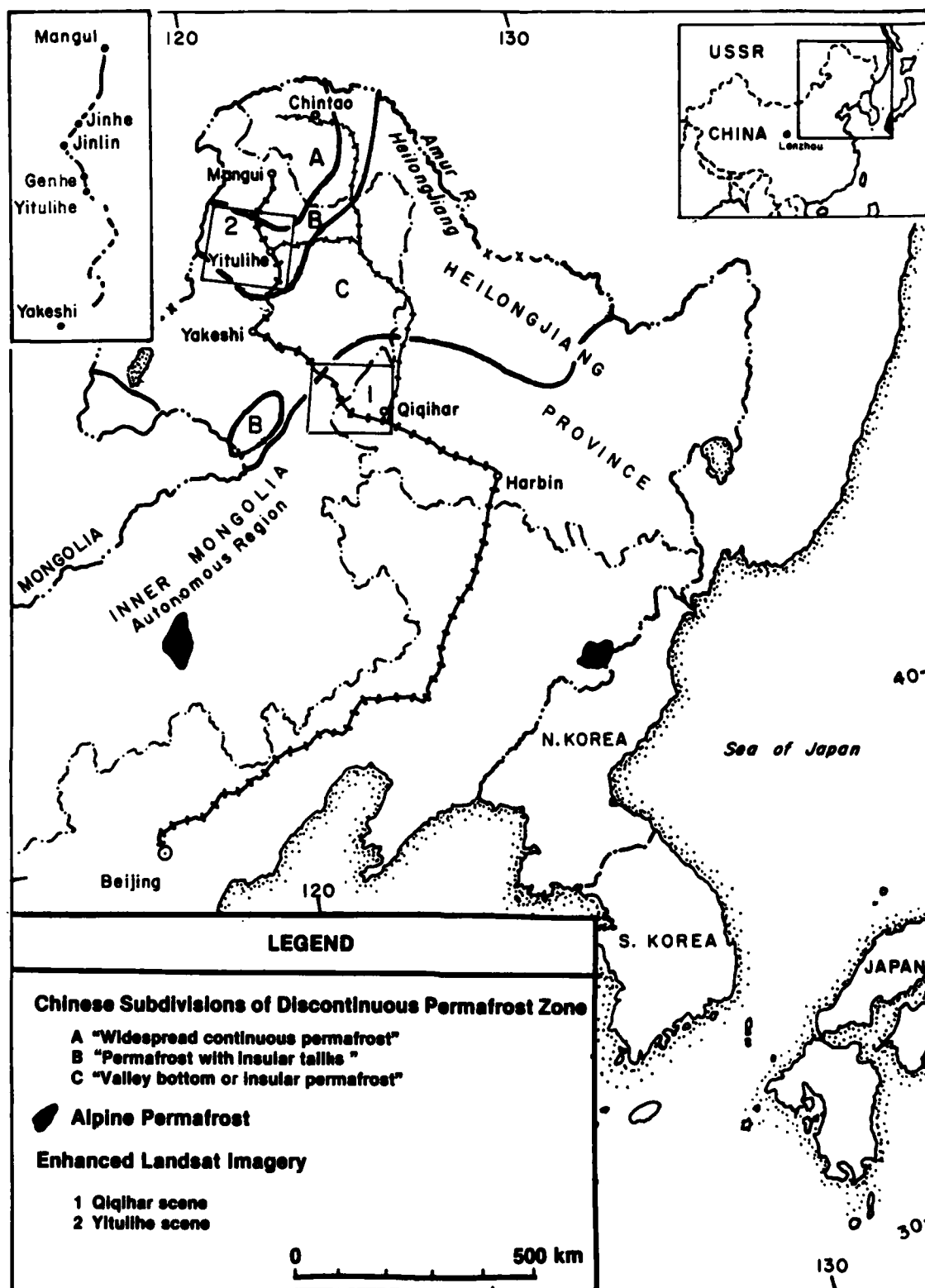


Figure 1. Map of northeast China showing distribution of permafrost (after Zhou and Guo, 1983), major rail routes, and locations of the enhanced Landsat scenes used during the July 1984 trip. Insert in upper left shows approximate location of permafrost sections (solid lines) along the Yalin Line route from Yakeshi to Mangui (after Qiqihar Res. Inst. of Sci. and Tech., 1984; see App. E). Chinese terminology for permafrost zones differs from North American and international usage. In this report, Chinese terms are placed in quotes.



the Fourth International Conference on Permafrost, but the actual experience of visiting institutes and field sites and participating in discussions with large numbers of Chinese specialists provided the opportunity to refine our own understanding of current engineering practices and their limitations, and of the distribution of permafrost in northeast China.

Clearly the design and construction of railways over permafrost is well advanced in China. Problems related to railway winter drainage, reduction in thaw settlement, and damage to culverts and bridges due to frost heave and settlement have been experienced and in many cases resolved. Large labor resources permit excellent maintenance of the railroad. Much of the railway in northern and western northeast China serve forestry needs, and specialized institutes and field stations have been established to obtain design data. Ventilated-slab and pile foundations are used for residential dwellings and other structures, although experience in these areas appears to be limited.

The distribution of permafrost in China was clarified by the visit. Considerable areas of northern Inner Mongolia are underlain by permafrost. This region should be considered to be in the northern part of the discontinuous permafrost zone. We observed ground-temperature observation wells in disturbed areas, and maps of ground temperature were provided.

Details of the 16-day visit are presented in this report based on input from the individual delegates. Ten of the U.S. delegates were hosted by the Ministry of Railways while in China. The other five were responsible for paying their costs in China, which amounted to approximately \$1000 each. The arrangements for the trip included a concurrent but separate visit by six family members of the delegates. This was unusual in that this private trip was arranged by a U.S. travel agency through the China International Travel Service (CITS) and was coordinated with the Ministry of Railways so that portions of the travel in Beijing, Xian, and Lanzhou could use common accommodations and other activities. In general, this worked well with only minor bureaucratic problems.



a.



b.

Figure 2. a) View of special four-car train provided by the Harbin Railway Administration. b) Photograph of delegation members, accompanying engineers, and the train crew. Photograph taken at Butha Qi (Zalantun) en route to Qiqihar, 23 July 1984.

## NORTHEAST CHINA

### GENERAL ROUTE DESCRIPTION

From Harbin, the field excursion (Fig. 2) took us northwest 875 km to Yakeshi through the Da Hinggan Ling<sup>1</sup> (Greater Hinggan Mountain Range). For the first 325 km, the route crossed loess and fine-grained alluvium underlying a broad, seasonally frozen, relatively flat fluvial plain at a general elevation of 170 to 210 m. Semivegetated sand dunes occur along the railroad between Ang'angxi and Hulan Ergi. This sand is derived from bars of the meandering Nenjiang He<sup>2</sup>. At Longjiang, the railroad starts up the low gravel terrace of the Yalu He, which it follows for 150 km to Butha Qi, the reported southern limit of valley-bottom or insular (island) permafrost. Near Butha Qi (Zalantun), the highest hills reach 1075 m elevation and vegetation is quite different on north- and south-facing slopes. Warmer, drier, south-facing slopes in the vicinity of Balin support a continuous grass cover with a few scattered birch trees. On the cooler, moister, north-facing slopes, birch-pine (or larch?) forest is continuous. Permafrost apparently does not affect the vegetation in this area. From Butha Qi north, the route traverses 120 km up the floor of the valley of the Yalu He to Bugt across low terraces and the lower slopes of alluvial fans. At about 900 m elevation the tracks leave this drainage and drop into the drainage of the Peitou He, following it for 105 km to Yakeshi (49°24'N) at about 750 m elevation. Several photographs taken along this route are presented in Figures 3, 4, and 5.

The mean annual air temperature at Yakeshi is -2.8°C and zones of permafrost are reported to be 3 to 23 m thick in this area, which is close to the southern boundary of widespread permafrost. However, it is reported that there is no permafrost within Yakeshi itself.

From Yakeshi, the route turns northeast and continues 160 km along low terraces of the upper Hailar He to Xinzhangfang (915 m elevation). The southern limit of widespread permafrost is crossed about 40 km northeast of Yakeshi. Near Xinzhangfang, the route crosses a low ridge and enters the headwaters of the Gen He. Fifteen kilometers farther is the town of

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<sup>1</sup> Ling = mountain range

<sup>2</sup> He = river



a. Double track with concrete ties. Retaining wall on left.



b. Tors in granite near Balin characteristic of intense periglacial weathering. (Photograph by Ray A. Kreig.)

Figure 3. Photographs taken along Pin Zhou rail route between Qiqihar and Yakeshi, 20 July 1984.

Tulihe. The valley-floor vegetation in this area is referred to by the Chinese as "tatao grass," a mixture of grasses, sedges, forbs, and low bushes. Hills and ridges are covered by a continuous mixed forest of birch, pine, and larch. The drainage basin of the Gen He is traversed for 85 km. About 25 km northwest of Tulihe is the key rail junction town of Yitulihe, built in 1956. At Yitulihe ( $50^{\circ}38'N$ ), permafrost is 50 to 70 m thick and at a depth of 13 m has a temperature of  $-1.3^{\circ}C$ . The depth to



Figure 4. On the rail route between Qiqihar and Yakeshi, 20 July 1984. Approach to Hsing An Tunnel, which is 5 km long and located at crest of the Da Hinggan Ling. The tunnel was built in the 1920's. Both entrances were fortified, presumably during the 1940's. (Photograph by Ray A. Kreig.)

permafrost is 0.6 to 1.0 m. The mean annual air temperature is  $-5.2^{\circ}\text{C}$ , and air-temperature inversions are reported to occur. The lower part of the town, which is located on a low terrace, is underlain by 0.7 m of peat over 2 to 5 m of frozen silt and clay over frozen gravel alluvium. The valley bottom vegetation is tatao grass. The surrounding bedrock hills support a birch forest with minor amounts of larch and pine growing over reportedly unfrozen terrain.

South of Jinlin, the route enters a northeast-flowing tributary of the Chin He and follows this drainage 130 km to Mangui, the end of the railway and the northernmost point on our tour. Between Yitulihe and Mangui, especially near Chaozhong, the route traverses coalesced gravel fans that extend westward from tributary valleys. Fine-grained, organic-rich cover deposits on these fans are from 0.2 to 0.3 m thick. They overlie angular to subangular pebble-cobble gravel, which is exposed in shallow excavations and the channels of small streams. This landform is particularly susceptible to the development of seasonal stream and slope icings. Permafrost conditions on these fans are not known. The lower limit of trees and bushes and the upper limit of tatao grass appear to coincide generally with the upper limit of shallow permafrost in upland valleys. Elsewhere, areas of heavy slope icings are marked by dead bushes and trees. To control seasonal slope icings, single or double interceptor ditches were dug 15 to 40 m upslope of the roadbed embankment. There does not appear to be any recent



a. Widening of bedrock cut in Hsing An tunnel area.  
(Photograph by Ray A. Kreig.)



b. Borrow pits along side of track. Excavated material presumably was used for rail bed. Rectangular pit shapes are reportedly an aid in managing quantities excavated by individual work crews. (Photograph by Larry Sweet.)

Figure 5. Photographs of rail route between Qiqihar and Yakeshi; 20 July 1984.

damage to the railroad in these areas due to icings. Within the Chin He drainage, the valley floor has a general elevation of 760 m. Hills reach 1450 m near Mangui, but the general ridgecrest elevation is about 900 m.

In Yakeshi, Kreig and Reger had the opportunity to examine stereoscopically about 100 black-and-white aerial photographs of excellent quality that were taken in the Mangui area in June-October 1954, two years before the railroad reached the area and Mangui was built. The scale was probably 1:25,000, because Fang (1980) reported that forest regions in northeast China were photographed at that scale in the 1950's. Landforms were observed that indicate modern, discontinuous permafrost, including (1) a single open-system pingo near the apex of an alluvial fan at the mouth of a tributary valley, (2) low-center ice-wedge polygons on valley fills associated with weakly beaded drainage, and (3) thaw-modified flood-plain lakes in former sloughs. Valley fills in the Mangui area appear very similar on black-and-white aerial photographs to valley fills in bedrock uplands to the east and north of Fairbanks that are not covered by loess. There is, however, much less evidence of thermokarst in the Mangui area, where the fills may either be coarse-grained and contain less ground ice or may be thinner. In our discussion at Yakeshi, Wen stated that there are palsas in the Mangui area up to 50 m wide and 10 m high and containing 2 to 3 m of layered ice. None were observed on the aerial photographs. Stabilized (forested and inactive) landforms, which indicate more rigorous former periglacial conditions, were also observed on the black and white photographs: (1) cryoplanation terraces, (2) large nivation basins, and (3) ridgecrest and valley-side tors. Stabilized block sheets on sloping granitic outcrops were also observed from the train. Most bedrock in this area is volcanic and intrusive rocks of Mesozoic age covered by 1 to 2 m of angular to subangular pebble-cobble colluvium. Organic surface deposits appear to be generally less than 0.4 m thick and discontinuous in the hills. River-valley fills are generally coarse-grained alluvium.

Two enhanced Landsat images of northeast China (Qiqihar and Yitulihe, Fig. 1) were brought to China for use during the trip. These 1:250,000- and 1:500,000-scale color-infrared images were specially enhanced to substantially improve clarity, resolution, geometric accuracy, and color balance, and they proved to be very useful as supplements on the trip as base maps for locating photographs and notes taken of features along the

route and stops arranged by our Chinese hosts. In the field, they provided a regional perspective on terrain characteristics, vegetation distribution, cultural features, and site environmental relationships that greatly aided the understanding of the significance of what was seen along the comparatively narrow corridor traversed. Even with better base maps than were available on the trip, it would not have been possible to identify the exact locations of photographs taken on the trip without these enhanced Landsat images.

Qiqihar Image (not illustrated in text) - The field trip route traversed the center of this scene from the southeast to northwest corners. The lowlands in the eastern half are largely treeless, either naturally or due to cultivation. Extensive tree plantations are clearly visible in many places. Wet areas used for rice cultivation and areas of wet and dry natural grasses can also be distinguished in this region. The western half of the picture includes part of the Da Hinggan Ling, which appear to be about 60% covered with deciduous forests. Flat-bottomed valleys are vegetated with scrub or grass. Many drier south-facing slopes are treeless grassland. One prominent cultural feature that is visible on the Qiqihar image (perhaps because of an adjacent road or tree hedge) is the Hsingan ("willow") wall, which forms the boundary between Heilongjiang Province and the Nei Monggol Autonomous Region (Inner Mongolia). It is traceable across the entire image from the southwest to the northwest. However, remains were not seen on the ground where it crosses the railroad route between Nianzishan and Butha Qi.

Yitulihe Image - This image covers rolling to moderately high mountains (Fig. 6). The southwestern quadrant (Ergun Youqi) is not forested and reportedly lies in the zone of "insular permafrost." Approximately 10% of this area is in agriculture. Many fields are uncharacteristically large, up to 2.3 x 4 km, and they appear to be part of massive agricultural development projects. Some fields have been laid out in straight lines without regard to the natural sloping topography. Portions of the wall of Genghis Khan cross this area. The rest of the image shows no agricultural development, with the exception of a small area around Orqohan in the southeast. Several areas with small lakes in valley fills are observed. The most prominent area is 25 km south-southwest of Yitulihe. These valley fills may be finer grained and contain more ground ice than those in the



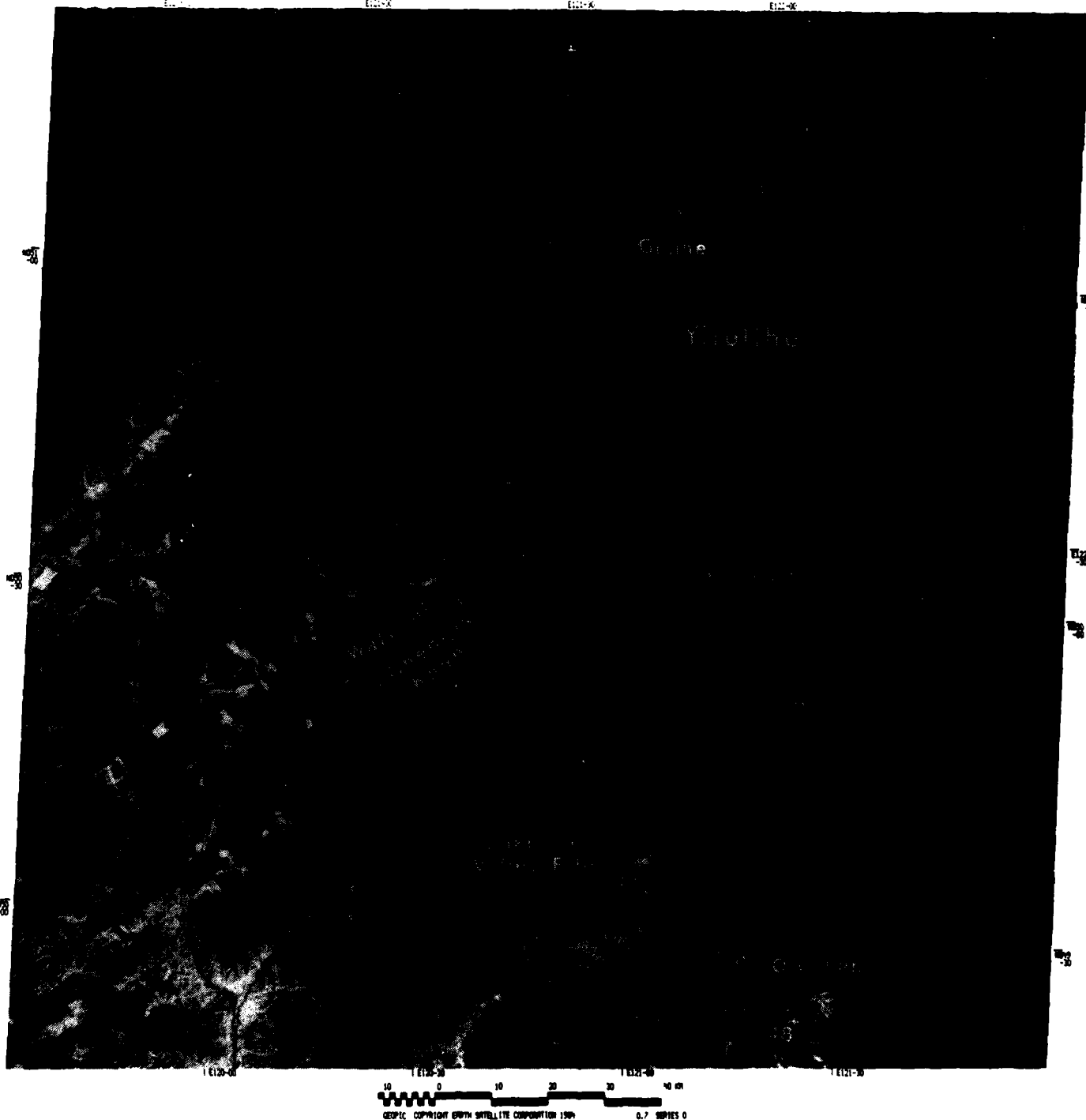


Figure 6. Black and white print of Yitulihe enhanced Landsat scene (GEOPIC™ image prepared by Earth Satellite Corporation). Scale 1:1,000,000. The Yalin rail route is marked on the photograph. Spot elevations in meters.

Mangui area, north of this scene. They are very similar in size, shape, and location to lowland thaw ponds and lakes in the Fairbanks area.

The remainder of the scene is forested except on valley bottoms and drier south-facing slopes. It is in the discontinuous permafrost zone. Population is concentrated in sizeable settlements spaced 20 to 25 km apart on the railroad. There are very few settlements visible on the image away from the railroad. Observations made from the train indicate that very few people reside outside of settlements; isolated houses are very rare.

The forest growing on uplands over most of the image consists primarily of second- (or perhaps third-) growth deciduous trees, which from the train appeared to be primarily birch. Since construction of the Yalin railroad and associated logging spurs in adjoining valleys in this area in the 1950's and 1960's, exploitation of the forests has led to the cutting of old growth (which appears to show on the image as very dark red). It is thought that this forest is composed of larch and Siberian pine. As of the image date of 1977, only about 5% of the area of the scene remained in this vegetation type, which in most cases is in remote areas away from the railroad. Boundaries of one area in this vegetation type near the northeast corner of the scene correspond to a drainage basin. It may represent a research drainage basin, reserve, or natural area. Harvesting patterns, which consist of linear clear cuts in a repeating pattern generally up and down slope, are clearly visible in the picture. Several old burns are present but preliminary analysis indicates that fire does not appear to be as common as it is in the interior Alaskan taiga.

Field sites visited along the 440-km-long Yalin rail route to Mangui were:

Stop 1 - 318 km - Bridge at Jinlin that has experienced subsidence and frost heave

Stop 2 - 323 km - Roadbed stabilization and culvert construction (Wang, 1982)

Stop 3 - 437 km - Relocation of bridge due to winter icing

Stop 4 - 439 km - Slope stabilization and underdrainage

Stop 5 - Mangui - End of rail line, examples of foundations on permafrost

Stop 6 - Yitulihe - On the return trip; foundations on permafrost and the Frozen Ground Observation Station.

In 1977, the Canadians visited a permafrost station at Chintao (Jintao) along the Liun Kiang rail line (Fig. 1) and sites along the Yalin

route that included:

- 44 km - Large semi-permanent icing that heaved the railbed. The roadbed was relocated to avoid the icing and large masses of ground ice.
- 177 km - The 936-m long Lingding tunnel. Freezing of groundwater resulted in cracking of the tunnel walls. A drainage system was constructed beneath and outside the tunnel to lower the groundwater table and remove surface water (Nei, 1983).

## PERMAFROST CONDITIONS

### Distribution of Permafrost and Frozen Ground

Permafrost underlies 2,150,000 km<sup>2</sup> or 22.3% of the territory of China. The total area of perennially and seasonally frozen ground (the depth over 0.5 m) occupies 68.6%. Generally, permafrost in China can be divided into two broad categories: permafrost in high latitudes and permafrost in high altitudes (Fig. 7). Within these two categories the classification of permafrost in China is based primarily on areal distribution and not on mean annual ground temperature.

The permafrost region in northeast China is part of the southernmost zone of the Eurasian continental high-latitude permafrost area. It lies in the discontinuous zone on the international permafrost map of the Northern Hemisphere (Fig. 8). As in other places in the world, frozen ground in the discontinuous zone conventionally becomes more widespread and thicker northward from its southern margin. This distribution of permafrost depends on latitudinal zonation. The mean annual ground temperature rises southward. Generally, with a 1° decrease in latitude, the mean annual air temperature and the mean annual ground temperature will increase 1 and 0.5°C, respectively. Farther south on Figure 1, the continuity of permafrost goes from "widespread continuous"<sup>3</sup> to "island permafrost."<sup>4</sup> The southern limit of permafrost is between 46°36' and 49°24'N latitude. Alpine permafrost occurs in mountains south of this limit.

The distribution of permafrost in northeast China varies from occasional small, thin frozen bodies of sediment in poorly drained valleys at the southern border of the permafrost region to widespread, thick perma-

<sup>3</sup> As noted previously, to avoid confusion between Chinese and U.S. usage, Chinese terminology is given in quotation marks.

<sup>4</sup> "Insular," "island," and "isolated" are apparently used interchangeably to denote the same zone.

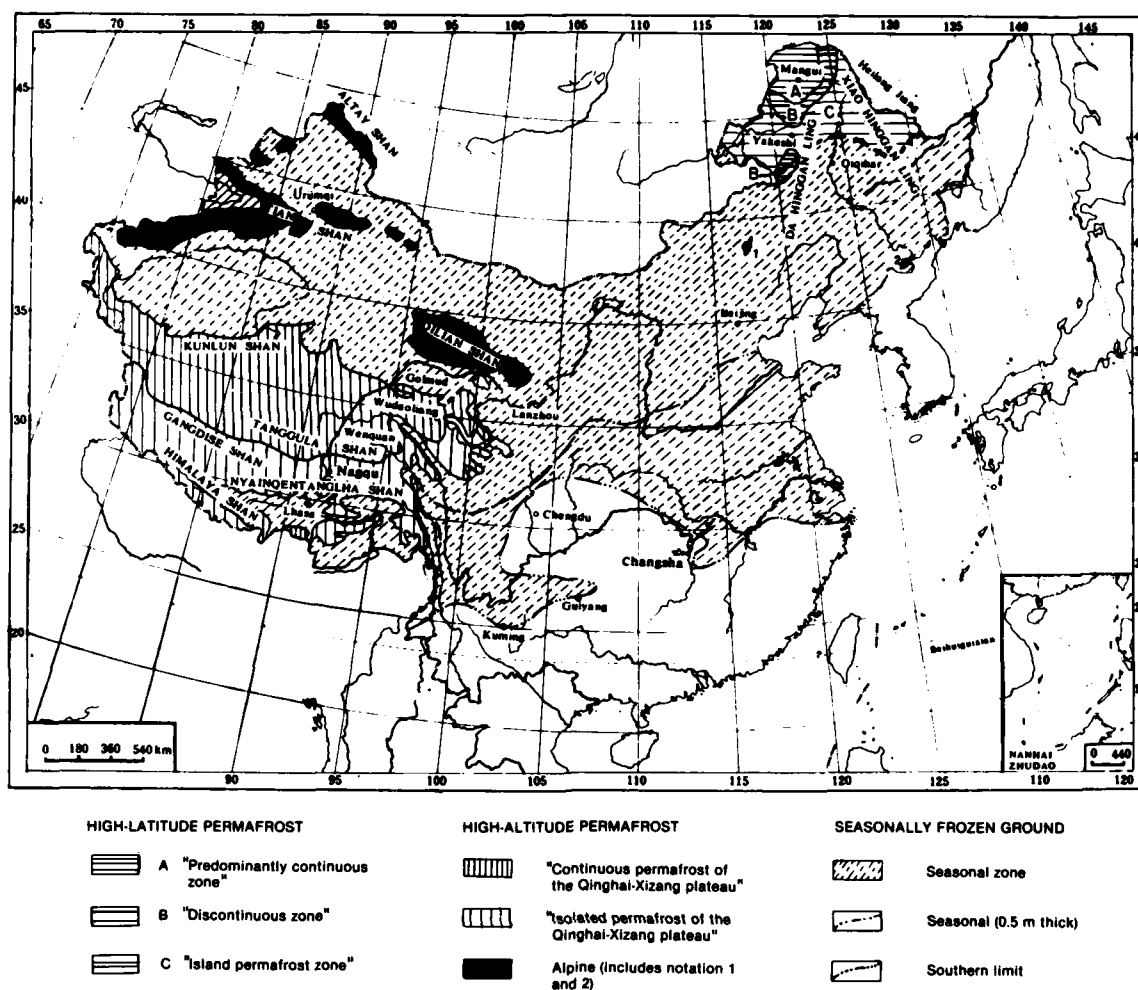


Figure 7. Types and distribution of permafrost and seasonally frozen ground in China (after Zhou and Guo, 1983). See text and figures for discussion on terminology for high-latitude permafrost in northeast China. Legend for this figure is slightly modified from the original.

frost in valleys and mountains near the northern border of China with the Soviet Union (53°N) (Table 4). Permafrost underlies 38,000 km<sup>2</sup> of northeast China (Lu et al., 1983) and extends 780 km north-south in the western part and 600 km north-south in the central part. Southward-trending mountains in the western and eastern part of the area cause the permafrost to extend farther south than in the central portion of northeast China, which is occupied by a plain. The southern permafrost border used here is after Lu et al. (1983) and is slightly farther north than the border of Cui and Xie (1984). The southern limit is 130 km north of Qiqihar and 450 km north of Harbin.

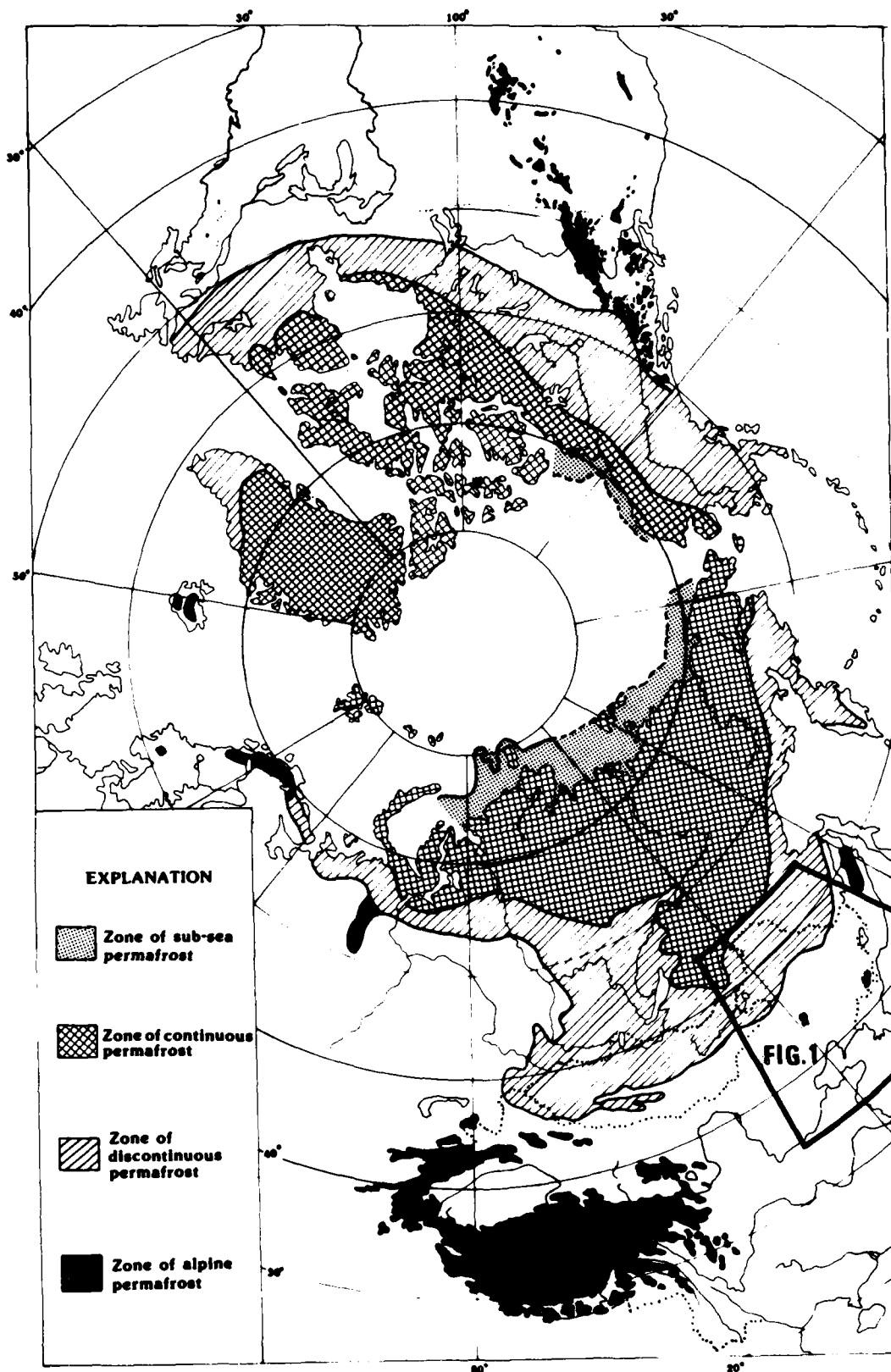


Figure 8. Distribution of permafrost in the Northern Hemisphere. Isolated areas of alpine permafrost not shown on the map exist in high mountains and outside the map area in Mexico, Hawaii, Japan and Europe (modified from Péwé, 1983).

Table 4. Air and permafrost data from selected locations in northeast China (from Lu, 1984).

| Site     | Latitude (N) | Elevation (m) | Mean annual air temp. (°C) | Thickness of permafrost (m) | Mean annual ground temp. (°C) |
|----------|--------------|---------------|----------------------------|-----------------------------|-------------------------------|
| Yakeshi  | 49°24'       | 667           | -2.8                       | 3 - 23                      | -0.5                          |
| Yitulihe | 50°38'       | ~ 800         | -5.2                       | 50                          | -0.8                          |
| Niuerhe  | 51°32'       | 988           | -5.0                       | 70                          | -2.3                          |
| Mangui   | 52°02'       | 880           | -4.8                       | 100                         | -4.2                          |

Two small areas of alpine permafrost occur as far south as 44°N latitude in the Changpai and Huanggangliang Mountains of northeast China but are not considered in this discussion (Figs. 1 and 9).

According to Chinese classification, latitudinal permafrost in northeast China is divided into three types from south to north: (1) "valley-bottom or insular (island) permafrost," (2) "permafrost with insular taliks," and (3) "widespread continuous permafrost" or "large-patch continuous permafrost" in two zones (Lu et al., 1983; Lu, 1984). Figure 9 compares permafrost zonation in Alaska (international terminology) and

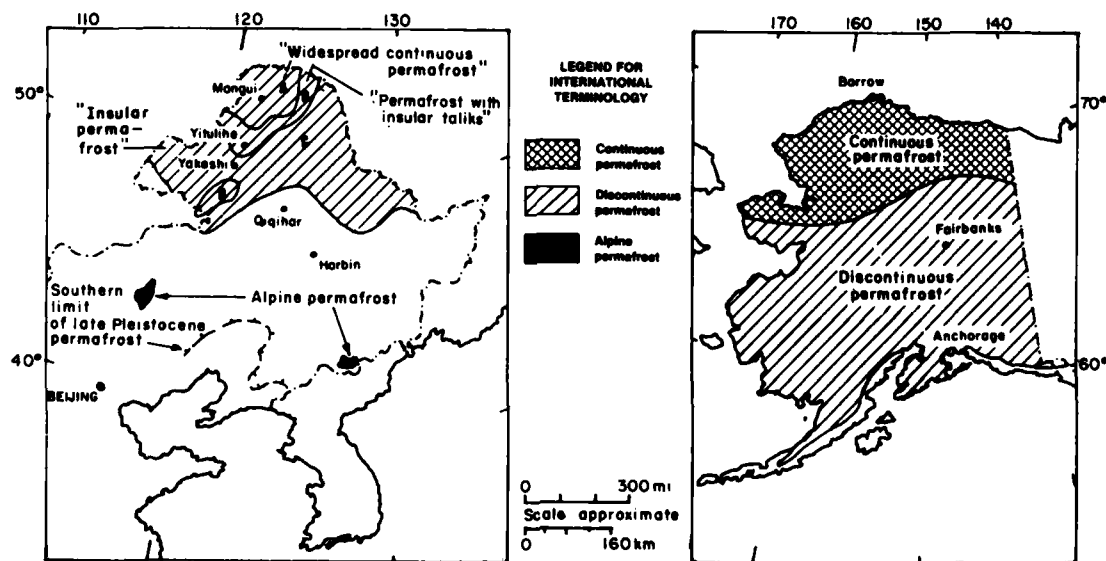
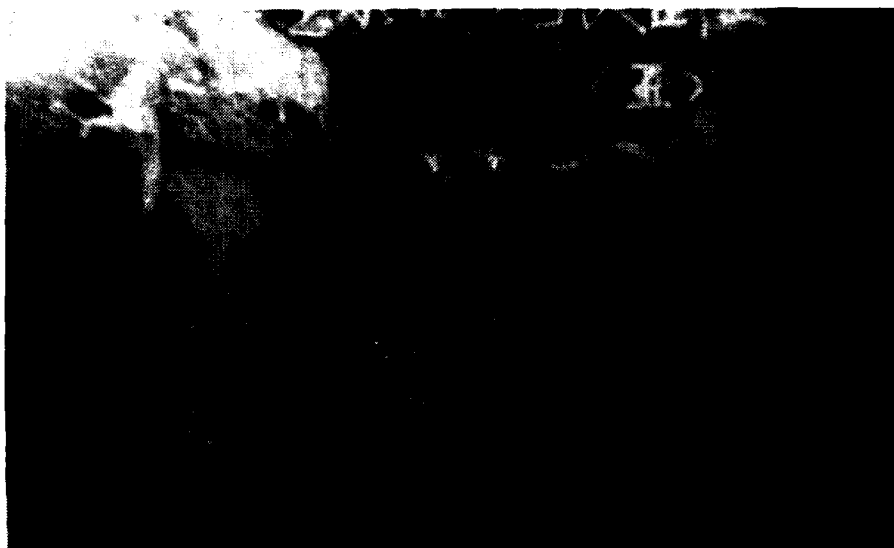


Figure 9. The distribution of permafrost in northeast China and a comparison with Alaskan permafrost zones. The two maps are at the same scale. Zones A, B and C are referred to in the text. Note differences in terminology for the permafrost zones between China and Alaska. All permafrost areas in northeast China are considered to be included in the discontinuous zone as defined internationally.

northeast China (Chinese terminology). "Widespread continuous permafrost" (zone A) in northernmost northeast China was assessed by the delegation to be most comparable to the discontinuous upland permafrost conditions in interior Alaska. Each Chinese zone is discussed below:

- "Widespread continuous permafrost" or "large-patch continuous permafrost." This type of permafrost is present in zone A, the far northwest part of the area with permafrost in northeast China (Fig. 9). Permafrost occupies up to 80% of the zone, being locally absent on south-facing slopes and under large rivers. Pingos are reported to be present north of Mangui (Lu, 1984). As indicated, Reger and Kreig (oral commun. 7/21/84) briefly examined aerial photographs of the area around Mangui and recognized an open-system pingo, weakly beaded drainage, forested cryoplanation terraces, and low-center ice-wedge polygons. Lu (1984, and oral commun. 7/21/84) reports thermokarst pits and layered ground ice in this area. At a briefing on 22 July, 1984, the delegation was shown a photograph of a 1-m wide ice wedge that had been encountered in an excavation under the permafrost observatory building in Yitulihe (see below).



- "Permafrost with insular taliks." This type of permafrost is present in zone B (Fig. 9). It is most common in valleys, but it also occurs on east-, west-, and north-facing slopes and occupies up to 30% of the zone (also described as less than 60%).
- "Valley-bottom or insular (island) permafrost." This type of permafrost is present in the southern part of zone C (Fig. 9). The area is considerably larger than zone A ("widespread continuous permafrost") and the area of "permafrost with insular taliks." It occurs in valley floors, lowlands, marshes, and abandoned sloughs as small bodies or "permafrost islands" and occupies 5-10% of the zone.

Summer excavations, which resulted in reports of frozen ground in valleys, were undoubtedly made at isolated localities from Manahouli to Butha Qi during construction of the Pin Zhou railway in the early 1900's.

With the modernization of this railroad and its extension into the forested areas north of Yakeshi in the 1950's, more information has been collected to give a better understanding of engineering problems associated with frozen ground there. Today, observations and research on the distribution and characteristics of permafrost in this area are made by members of the Ministry of Railroads, the Harbin Railway Administration, the Ministry of Forests, the Lanzhou Institute of Glaciology and Cryopedology of the Academia Sinica, and by members of Peking University and others.

#### Permafrost Thickness and Temperature

Permafrost becomes thicker from south to north. "Valley-bottom permafrost" is from 1 to 10 m thick, and locally 15 m. "Permafrost with insular taliks" may be up to 50 m thick, but generally only 30 m. In the north, "widespread continuous permafrost" is up to 80 m thick, and locally more than 100 m (Guo and Li, 1981; Table 4). It is less than 20 m thick or locally absent on south-facing slopes.

Temperature is an important characteristic of permafrost and permits comparisons from one place to another throughout the world. In addition to excavation and drilling, temperature is the only positive method for establishing the existence and thickness of permafrost. Temperature has long been used in classification of permafrost zones and is critical in evaluation of permafrost for engineering needs. The  $-5^{\circ}\text{C}$  mean annual ground temperature has traditionally been used to separate the continuous and discontinuous permafrost zones. It is customary to refer to the temperature of permafrost as that which occurs at the level of zero amplitude, that is, the depth at which significant variation between winter and summer ground temperatures is no longer present. This depth ranges between 10 and 25 m. More recently, the relative portion of permafrost and unfrozen ground has been used to define permafrost zones.

At Mangui, Yitulihe, and Harbin, ground temperatures taken from mercury thermometers on a cable that are pulled from pipes in the ground were observed. The Canadians also reported use of thermocouple cables in Chintao. This may also be the case on the Qinghai-Xizang Plateau.

Sufficient ground temperature data are available from northeast China to permit the following generalizations. In "valley-bottom permafrost," ground temperatures are from  $0^{\circ}$  to  $-1^{\circ}\text{C}$  (Lu, 1984), and in "insular permafrost with taliks," the mean annual ground temperature is  $-0.8^{\circ}$  to  $-2^{\circ}\text{C}$ . In "widespread continuous permafrost," ground temperatures are lower



than  $-2^{\circ}\text{C}$ , with the lowest temperature of  $-4.2^{\circ}\text{C}$  recorded at Mangui (Table 4). A temperature of  $-3^{\circ}\text{C}$  is thought to be average (Lu, 1984). Lu realizes this zone is not in the conventionally defined continuous permafrost zone, which lies 100 km to the west and north of the border with the Soviet Union.

In the late Pleistocene, permafrost was more widespread, thicker, and colder in northeast China than today. With the world-wide lowering of temperature and the withdrawal of the Yellow Sea, a colder climate permitted the southern border of permafrost to move about  $10^{\circ}$  of latitude farther south (Lu et al., 1983) (Fig. 9). Cui and Xie (1984) indicate the southern border to be even slightly farther south.

#### OBSERVATIONS OF ENGINEERING PRACTICES AND PERFORMANCE, YAKESHI TO MANGUI

During discussions with personnel of the Yakeshi Forest Survey and Design Institute, it was indicated that the Chinese construct several kilometers of new forest roads each year. They maintain several thousand kilometers of forest roads and are responsible for roads within cities and towns in the forest. Forestry representatives were very interested in our presentations about road construction in permafrost regions. Wen Peisheng presented a paper on the design of roads in forests. In general, they attempt to locate roads on south-facing slopes where the driest soils are located. When a valley is crossed, a thicker embankment is used. Ice-rich soils and high groundwater conditions are avoided when possible; if these route conditions are unavoidable, thick embankment fills are used rather than cutting into ice-rich soils. Poor materials are undercut and removed in some locations. Peat layers are also used as insulators beneath some embankments. Synthetic thermal insulating layers apparently are not used and there was considerable interest in the insulation samples we passed around for examination.

None of the rural roads observed during the trip was paved, but some streets in the city of Yakeshi were paved with concrete. Although not very old, they were performing satisfactorily. On some older paved streets minor settlement had occurred and water was ponded several centimeters deep.

Only a few kilometers of new railroad embankments are constructed each year. Construction of railroad embankments are generally associated with development of forest resources. It is guided by standards that are avail-

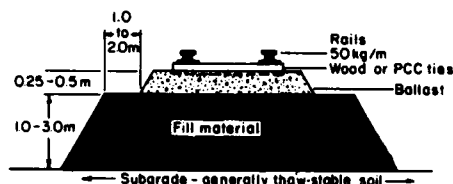


Figure 10. Cross section of typical railroad embankment in northeast China.

able in textbooks and were referred to as "Railroad Design Standards" and "Detailed Rules and Regulations of Railroad Survey and Design." In general, the railroad fill material was 2 to 3 m thick with 0.25 to 0.5 m of ballast placed on top (Fig. 10). The fill material was generally 1.0 to 2.0 m wider than the ballast. People use the shoulders for walking, transporting light goods, and bicycling. The railway embankment and rails are in excellent condition. Along the route, crews were seen gauging the rails and operating equipment for tamping ballast beneath the ties. The fill material was probably locally available. In many instances, it appeared to be silty or clayey sand. Usually the fill contained very little gravel-size material. The ballast was very clean crushed stoned from quarries along the route. At Butha Qi (Zalantun) south of Yakeshi, essentially all the work in the quarry was done by hand, including loading of cars. At some railroad sidings we observed crushed rock being delivered in tractor-drawn wagons and horse-drawn carts. A bulldozer was used to push the crushed stones into larger stockpiles.

The following information is presented according to the stops made between Yakeshi and Mangui.

Stop 1 (318 km) (Fig. 11, 12). A bridge 51 m long with one pier at the centerline of the stream was observed. Short-span bridges such as this one and elsewhere show design failure that is indicative of in-stream pier frost heave or bridge abutment footing settlement, or both. The bridge design is shown in Figure 13. The heavy bridge abutments are resting on a stone foundation about 5 m below the natural grade. There has been settlement in the south abutment foundation, probably due to degradation of permafrost and thaw settlement. Either the design bearing capacity of the soils was lower than expected or the permafrost is degrading in this area. Temperature data have been collected in the area of the foundation base and riverbed.

The bridge piers and abutments were placed on footings during the period of rail construction when pile-driving equipment was not available. By U.S. design criteria, the pier weight plus one-third the design load of



Figure 11. Stop 1. Steel plate girder bridge at 318 km on the Yalin Line. Access tubes in river and abutment are used to measure temperatures. Permafrost has been degrading under the riverbed. (See Figure 13 and text for details of bridge design and performance.)

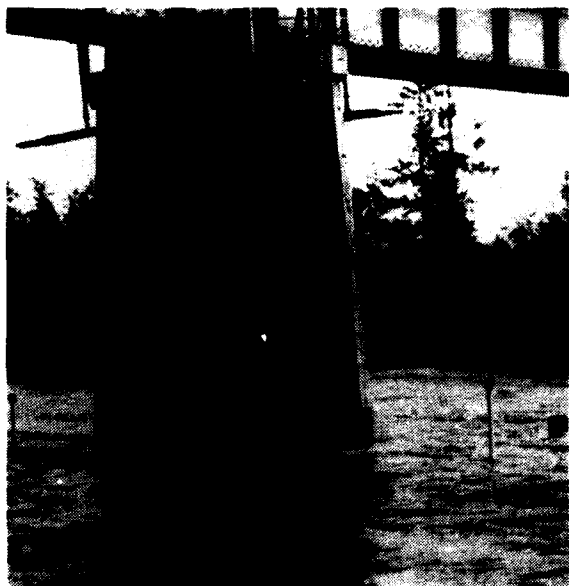


Figure 12. Stop 1. The bridge at 318 km. Access tubes in the river and abutment are used to measure temperatures.

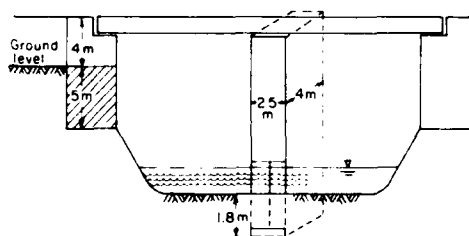


Figure 13. Design of the bridge at 318 km.

the bridge structure would be insufficient to resist seasonal heave forces: piles that penetrate well below the footing would be required for added resistance. The length of these piles would depend on soil conditions and the presence or absence of permafrost.

Stop 2 (323 km). We observed the only area where significant subsidence due to permafrost degradation was occurring. The Canadian delegation visited this site in 1977. During a 20-year period, ending in 1976, settlement had reached 1.4 m. In an 11-km section, 7 km had settled, causing great maintenance difficulties. Permafrost is widespread here and 60 m thick. The surface peat layer is 0.4 to 1.0 m thick overlying sandy clay 1.1 to 3.5 m deep. The moisture content is very high, reportedly ranging

from 40 to 80% but sometimes as high as 300%. Ice layers 2 to 50 mm thick containing soil were encountered, underlain by sandy clay with a moisture content below 40%. The permafrost table was at a depth of 0.9 m. The mean annual ground temperature at a depth of 5 m is reportedly  $-3.3^{\circ}\text{C}$ .

The subsidence problem was attributed to groundwater thawing the permafrost beneath the embankment. The treatment was to install a ditch approximately 1 m deep, 15 m from the tracks (Fig. 14). The area between the ditch and the embankment was covered to a depth of 0.4 to 1.0 m with peat and has since been overgrown by tatao grass. The surface of the peat was sloped toward the ditch to minimize the amount of water flowing into the embankment.

The Canadians reported that on the basis of observations made in 1976, the subgrade settled 96 to 169 mm from June to October. From November to January of the next year, frost heave of 34 to 44 mm occurred. The permafrost table under the grade depressed in a concave shape to a maximum of 1.75 m, forming a thaw basin. In the section where serious settlement occurred there was always free water in the thaw basin under the grade and considerable infiltration of surface water into it. Because the temperature of the surface water was high in summer, heat was introduced, causing the permafrost table to depress each year.

The railway engineers reported that because the site is now settling at a rate of about 10 mm/month during the summer, the treatment was successful. It was apparent that the treatment applied here had not stopped permafrost degradation in the seven years since the Canadian visit, but although heave and settlement have apparently occurred each year, the embankment did not show any obvious signs of failure, nor did we observe major signs of embankment degradation anywhere along the route. However, this may have been masked by the many years of maintenance.

Stop 3 (437 km). Winter icings had damaged the railroad. The railroad bed had been moved about 50 m downstream to avoid icing. Ice reached thicknesses of up to 3 m in the stream. Relocation of the railroad bed solved the problem (Fig. 15), although the new bridge does show minor cracking due to frost heave or thaw settlement.

Culverts are used for smaller streams. These consist of reinforced-concrete tube culverts with interlocking joints, and box culverts with timber walls and concrete beams over the top. The diameter of the former is usually 1.0 m, and 2.0 m in areas where there are icings. In the

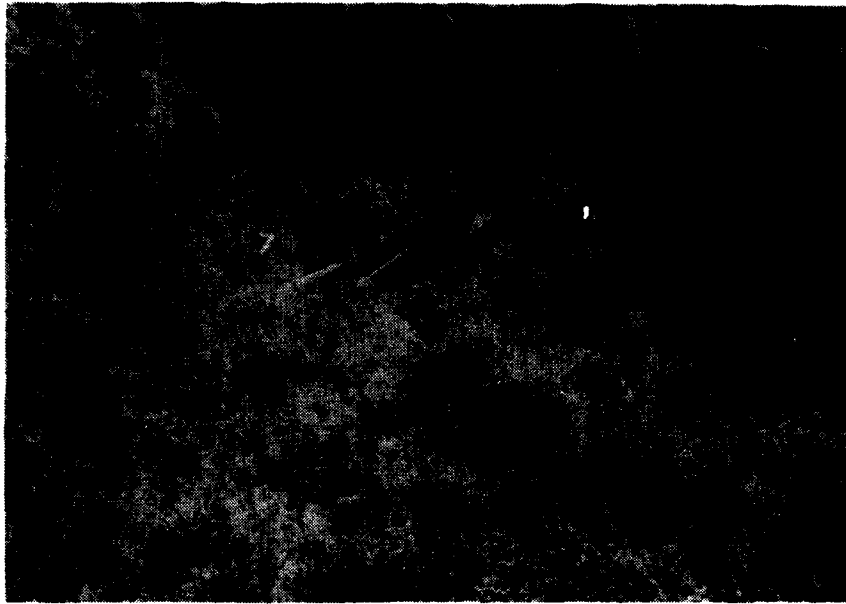


a. Tatao-grass-covered slope that has up to 1.0 m peat protective layer. A drainage ditch 15 m from the embankment diverts water.



b. Characteristic roadbed in this area. Wood rail ties will be replaced with concrete ties. Drainage ditch is seen on left side. (Photograph by Ray A. Kreig.)

Figure 14. Stop 2. Road stabilization at 323 km, 22 July 1984.



a. Abandoned wooden bridge.



b. A concrete bridge was constructed and the railroad bed was moved approximately 50 m downstream, eliminating the icing problem.

Figure 15. Stop 3. Site of relocation of railroad bridge at 437 km, 22 July 1984. Relocation was required to prevent damage caused by winter icings that were 2-3 m thick.



Figure 16. Stop 2. Concrete culvert observed at 323 km, 22 July, 1984.

latter, masonry wing wall is used, cutting into the embankment slopes. These culverts are 1.0 or 2.0 m in diameter in areas where icings exist upstream. The paper by Teng Jiajun discusses culverts in detail (Appendix D). Culvert construction and maintenance problems were observed at stop 2 and further illustrated in examples provided at Qiqihar (Fig. 16, 17).

Stop 4 (439 km). This is the site of an icing problem related to the cut made when constructing the new line in 1964. After completion, a large quantity of water flowed from the slope, forming icings in winter and covered the rails. This once resulted in derailment of a train. The natural surface where the cut was located had a slope of 15 to 20°. A peat layer 0.3 m thick covered water-bearing sandy gravel 1.2 m thick above sandy clay. The permafrost table was 1.75 m deep. To remedy the icing problem, a longitudinal insulating leaching ditch 120 m long by 2.5 m wide was built under the righthand ditch of the line in 1973. A permeable layer of sand and gravel was also laid on the surface of the right slope so that water seeping from the slope would flow into the leaching ditch. On top of the permeable layer was an insulating peat layer 0.5 m deep above which was placed a protective lining of dry rubble. At the end of the ditch, a



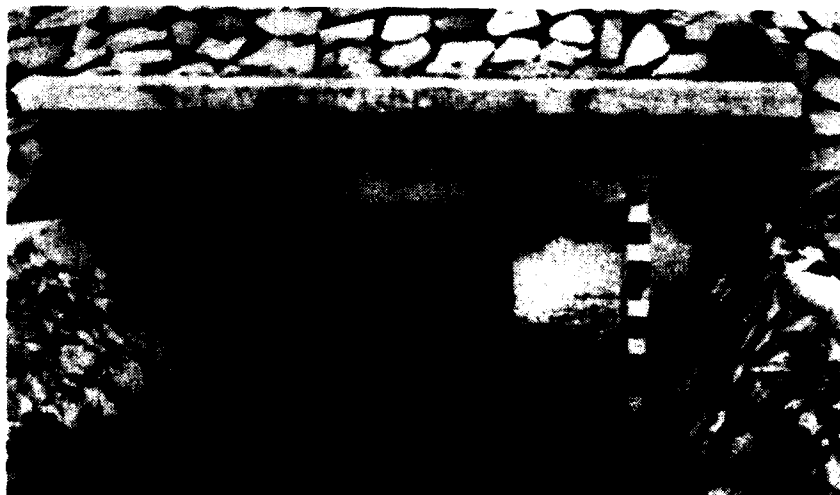
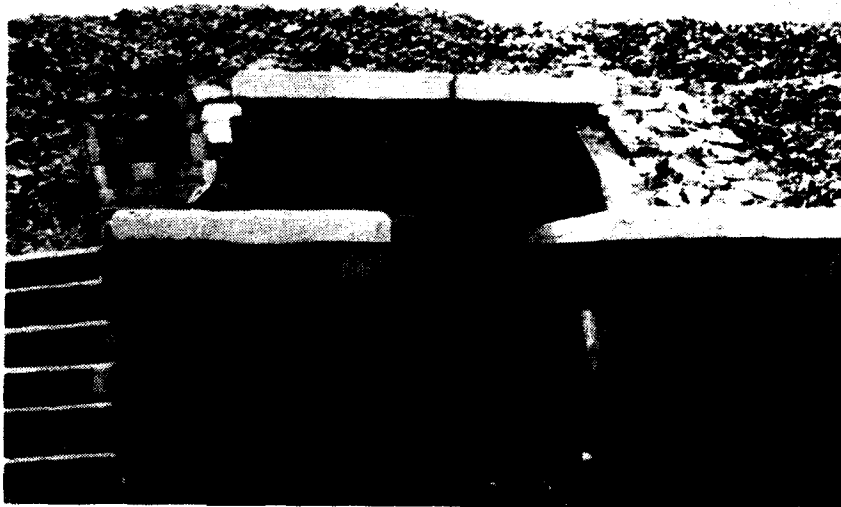
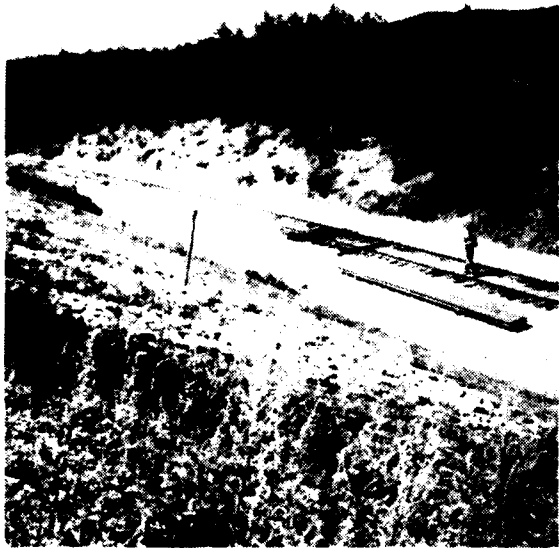


Figure 17. Culvert failures and construction techniques.  
(Photographs provided at Qiqihar.)



a.



b.



c.



d.

Figure 18. Stop 4. a) and b) Slope stabilization at 439 km, 22 July, 1984. Underdrains are used to remove excess water that had previously caused serious icings on the track. See text for discussion. c) Slope movement is evident as rock-lined drainage ditch is now almost completely closed. d) Another example of rock-lined drainage channels.

concrete culvert, which was an open ditch above and a blind ditch below, crossed the line. An insulating cone was built at the outlet of the blind ditch to lead groundwater to the ground surface. The leaching ditch was completed in 1973 and apparently is performing well; the outlet has not frozen in winter and no water has seeped from the slopes of the cut. The formation of icings and damage from freezing have been eliminated. One section of the repair about 10 m long had moved downslope to reduce the size of the ditch (Fig. 18).

Stops 5 and 6. Pile-supported structures were viewed at Mangui and Yitulihe. The structures were either under construction or recently completed. At Yitulihe we visited the Frozen Ground Observation Station (Fig. 19 and 20). Buildings utilize concrete piles, reinforced concrete



a. The Frozen Ground Observation Station.



b. The station's climatic and ground temperature site across from the laboratory.

Figure 19. Stop 6. Yitulihe.

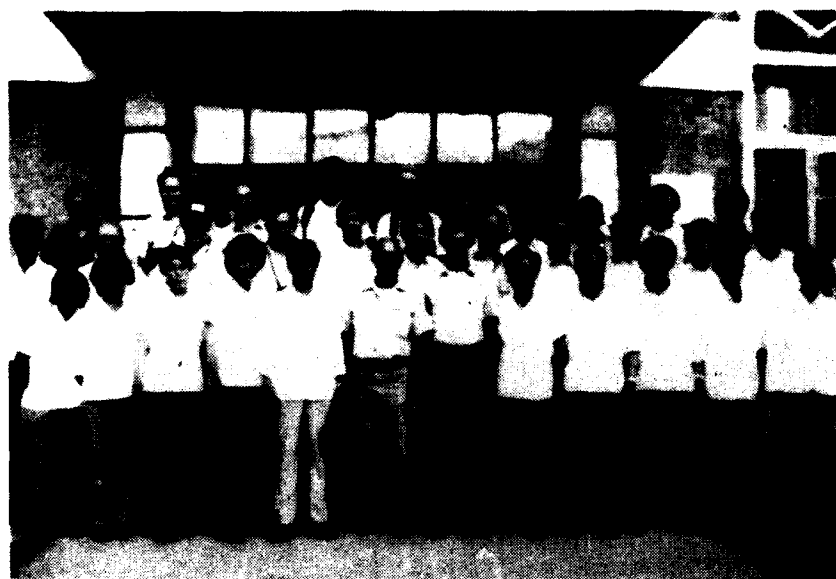


Figure 20. Stop 6. Group photograph of delegation, accompanying engineers, and the station's staff, taken at Yitulihe Frozen Ground Observation Station.

floor slabs, and common brick construction. The brick is manufactured locally. Walls are approximately 1 ft thick with no insulation. Windows are large with double frames and panes and not well sealed.

The pre-cast reinforced concrete piles were installed by driving them into a smaller diameter, pre-drilled hole or by installation in an oversized drill hole with native-soil backfill. Discussions indicated that piles were driven if the total length was less than 4 m and the frozen ground was suitable for driving. All longer piles (7 m at Mangui and Yitulihe) were installed in pre-drilled, oversized holes backfilled with native soil or a mixture of soil and cement (Fig. 21). It was clear that adfreeze along the pile was assumed for support, but there is some end-bearing contribution in the design.

The concrete piles used at Mangui for apartment buildings and the railway station are 7 m long, 30 cm in diameter, and installed in pre-drilled holes 38 to 40 cm in diameter. The annular space around the piles is backfilled with natural soil, perhaps in a slurry, and occasionally a soil-cement mixture. Concrete pile caps are cast in place after pile placement, probably to facilitate leveling and alignment of the structural concrete beams.

The active layer thickness at Mangui is 1.5 to 3.0 m with ground temperatures of approximately  $-2.0^{\circ}\text{C}$  at a depth of 20 m at the building



a. Group of 7-m long prefabricated, reinforced, concrete piles. (Photo provided at Qiqihar.)



b. Slab placed on piles as observed on 22 July 1984.

Figure 21. Stop 5. Examples of pile foundations at Mangui.



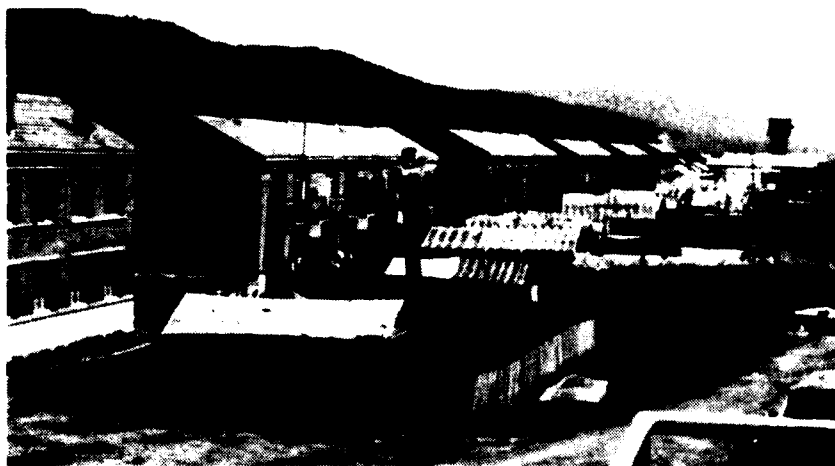
Figure 22. Stop 5. The ventilated foundation of the new Mangui railroad station soon after construction. (Photo provided at Qiqihar.)

site. Pile tests conducted at Mangui for a period of one year (with small load increments added weekly) indicated that each 7-m pile could safely support 22 metric tons of long-term load.

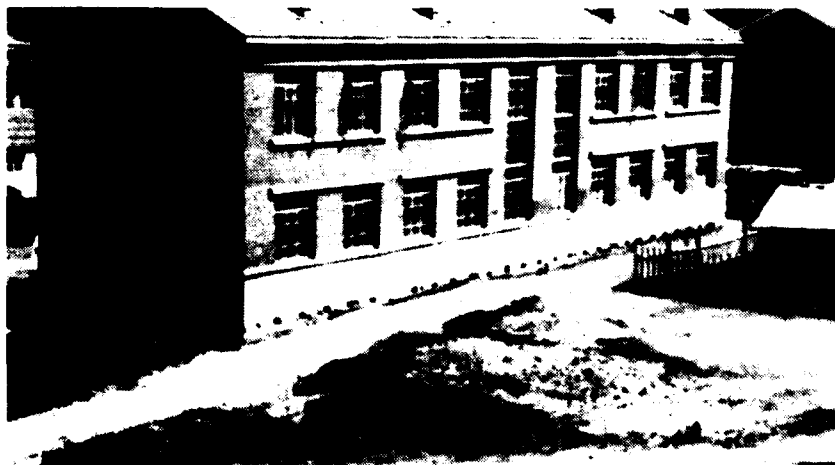
The pile-supported railway station at Mangui (Fig. 22) was designed



a. Main street.



b. Overview of new brick apartment houses.



c. View of ventilated foundation.

Figure 23. Stop 5. Mangui, town of 30,000 people at the end of the Yalin line, 22 July 1984.



Figure 24. Stop 6. Yitulihe. Slab and ventilated foundation. Openings are sealed in summer.

with an open air space of 1 to 1.5 m under it. The addition of an unheated storage room beneath the station apparently was considered to be a sufficient thermal barrier by the designer to allow soil to be moved around the air space, thus blocking air flow. This alternative is likely to adversely affect long-term performance of the station foundation, especially if air is not allowed to flow through the storage area and the area is not kept at ambient temperatures. Apartment buildings at Mangui (Fig. 23) and Yitulihe (Fig. 24) were designed to allow some air circulation through small vents on both sides. The foundation was enclosed with concrete slabs with ventilation holes approximately 10 by 25 cm, spaced approximately 1 m center to center. No covers were noted on these ventilation holes. Some of the vents had been blocked by residents of the apartments. Even with proper management it is unlikely that ventilation is adequate, although no information was available concerning heat flow from the building floor to the ground.

The building floor above the air space in the apartment building was insulated with a type of perlite (volcanic glass). The approximately 4-cm thick layer of granular perlite is placed in squared partitioned forms directly below the floor.

The ground surface adjacent to all buildings was altered significantly



a. Delegation photograph.



b. Brick building near the railroad station showing crack in wall due to subsidence permafrost, 22 July 1984.

Figure 25. Stop 5. Mangui.

from the natural condition. There was no natural vegetation or insulating system adjacent to the buildings. This fact, coupled with possible poor circulation of air beneath the floor slabs, could result in a warming of the existing permafrost and possibly increase the thickness of the active layer.

Pile-heaving forces are apparently calculated on the basis of a criterion of 21 metric tons per  $m^2$  of pile surface. This is equivalent to 30 lb. per  $in.^2$ , which is similar to Soviet and U.S. data for warm permafrost ( $T > -5^\circ C$ ). A comparison of data supporting Chinese and North American criteria should be made. Comprehensive soil, moisture, and temperature data and complete descriptions of testing procedures will be



required for the comparison. On the basis of field test results such as at the Wanjia Frozen Soil Field Test Station in Harbin, single pile lengths of 8 to 10 m in thawed soils are believed to be sufficient to resist the uplift force associated with a 1.8-m active layer.

#### TECHNICAL VISITS AND EXCHANGES

In addition to the train excursion to view actual permafrost and construction conditions, visits and exchanges with the following institutions took place while we were in northeast China:

- Heilongjiang Provincial Hydraulic Scientific Research Institute and its Wanjia Frozen Soil Field Test Station, Harbin.
- Heilongjiang Provincial Low-Temperature Construction Science Research Institute, Harbin.
- Yakeshi Forest Survey and Design Institute.
- Yitulihe Frozen Ground Observation Station of the Harbin Railway Administration.
- Qiqihar Research Institute of Science and Technology of the Harbin Railway Administration and its Low-Temperature Laboratory.

The visit to the Wanjia Frozen Soil Field Test Station in Harbin (Fig. 26) illustrated field testing of piles and foundations subjected to



Figure 26. Group photograph in front of the Wanjia Frozen Soil Field Test Station, 19 July 1984. The director of the Heilongjiang Provincial Hydraulic Scientific Research Institute is Zhou Xingwu (standing between Péwé and Berg, second row). The station manager is Xie Yinqi (extreme left, second row, with glasses). The director of the Heilongjiang Provincial Low-Temperature Construction Science Research Institute is Yuan Zhonghuai (between Rawlinson and Reger). Liu Hongxu (second from left, third row) attended the Fourth International Conference on Permafrost in Alaska.

Table 5. Questions Posed by Chinese During Technical Discussion at Heilongjiang Provincial Low-Temperature Construction Science Research Institute -- 19 July, 1984.

- 
1. How to classify the frozen soil according to its frost-heave characteristics in America?
  2. Should the frost-heave and frost-heave force be considered in seasonal frozen region? How to determine their values?
  3. Similarly theory about simulating test of frozen soil.
  4. How to measure moisture migration content in the soil freezing process? (Undistorted model measuring method of dynamic water content.)
  5. The measure of stress in frozen soil base.
  6. Laboratory test instrument.
  7. Countermeasures against frost hazard of building and structure in seasonal frozen region.
  8. Consideration of buried depth of building foundation in seasonal frozen region.
- 

deep seasonal frost penetration and heave. A well-illustrated video tape and slide presentation supplemented field observations. While in Harbin, the U.S. delegates presented several summary talks on frost heave, in-situ measurements, and pile foundations and responded to questions at the Low-Temperature Construction Science Research Institute (Table 5).

A one-day technical exchange took place at Yakeshi with each side presenting four talks. Topics covered permafrost distribution and mapping, and design, construction, and performance of railbeds, culverts, bridges, and building foundations. Table 6 contains the agenda topics covered. Four Chinese papers, two in English, were distributed. The edited version of the original English paper by Teng Jiajun is presented in Appendix D. The Chinese presented results of their field observations and successes and failures of structures associated with frost heave and permafrost degradation.

Two technical exchanges took place with the Qiqihar railway representatives, one on the train (Table 7) and one at the Low-Temperature Labora-

Table 6. Agenda for Technical Exchange at Yakeshi Forest Survey and Design Institute, Inner Mongolia — 21 July, 1984.

---

|           |  |
|-----------|--|
| 8:00 a.m. | Welcome and Introductory Remarks   |
|           | Xu Tiechuan, vice-director of Institute (and engineer)<br>Han Xuchang, director of Institute (and chief engineer)          |
| 8:30 a.m. | Session I - The Permafrost Environment   |
|           | "The Distribution of Permafrost in Northeast China," Lu Guowei   |
|           | "The Distribution of World Permafrost," T.L. Péwé  |
|           | "Mapping the Permafrost Environment Using Enhanced Satellite Images and Air Photos," R.A. Kreig                            |
| 9:30 a.m. | Session II - "Road Construction and Problems of Road Engineering in Permafrost Areas of the Da Hinggan Ling," Wen Peisheng |
|           | "Current U.S. Practice for Road Construction in Permafrost Areas," R.L. Berg   |
|           | "Current Research Work on Road Construction in Alaska," D.C. Esch  |
|           | "Use of Geotextiles in Cold Regions," T. Vinson  |
| 1:30 p.m. | Session III - Bridge and Culvert Engineering   |
|           | "Permafrost and Bridge-Culvert Engineering in the Da Hinggan Ling," Teng Jiajun  |
|           | "Bridge and Culvert Engineering in Permafrost Regions of Alaska," V. Manikian  |
| 3:00 p.m. | Session IV - Foundation Engineering  |
|           | "Problems of Building Foundations in Permafrost Areas of the Da Hinggan Ling," Zhao Lianzhong                              |
|           | "Building Foundations in Permafrost Regions in Alaska," M.C. Metz and R.E. Smith   |

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tory in Qiqihar (Table 8). A series of questions and answers was exchanged between the two sides on the train. In the final session at Qiqihar, the U.S. summarized ongoing and future frozen-ground research in federal and State of Alaska agencies and industry (Table 8). The Chinese concluded with a tour of the laboratory's large coldroom and material-testing facility (Fig. 27) and a slide show recapping the train trip, including sites

Table 7. Questions Posed by Chinese During Technical Discussion on Train Between Yitulihe and Qiqihar -- 23 July, 1984.

- 
1. What equipment exists to determine the depth to and thickness of permafrost in the U.S.?
  2. Can you use radar to determine the character of permafrost?
  3. Give concrete methods to define groundwater locations in permafrost areas.
  4. How many types of foundation do you use in permafrost regions?
  5. What is the direction of testing and research to evaluate geotechnical characteristics of permafrost?
  6. How do you design thermopiles?
- 

Table 8. Agenda for Technical Exchange at the Qiqihar Science and Technology Institute of the Harbin Railway Administration -- 24 July, 1984

- 
- |            |   |
|------------|---|
| 8:30 a.m.  | Welcome and introductory remarks, Miao Shiheng, director of Institute (and engineer)  |
| 9:00 a.m.  | <p>"Permafrost Research Needs in the United States," J. Brown</p> <p>"Permafrost Research Work at CRREL," R.L. Berg</p> <p>"Recent Research Activities at the Alaska Department of Transportation," D.C. Esch</p> <p>"Research Activities on Permafrost in Industry," M.C. Metz</p> <p>"International Cooperation of Permafrost Researchers," T.L. Péwé</p> |
| 10:00 a.m. | "Coldroom Test Facilities at the Qiqihar Institute," Liu Zhen, engineer (followed by a tour of coldrooms and test lab)  |
| 11:00 a.m. | "Summary of Permafrost Engineering for Railway Activities in Northeast China," Li Qixiu, engineer   |
| 11:45 a.m. | <p>Closing remarks</p> <p>Lui Fengnian, deputy chief engineer, Harbin Railway Administration</p> <p>Zhou Hongye, vice president, Chinese Academy of Railway Sciences</p>  |
-



Figure 27. Universal extension/compression load frame at Qiqihar Research Institute of Science and Technology of the Harbin Railway Administration; compression tests are conducted with the upper load plates and tension tests with the lower grips. (Photograph by Ray A. Kreig.)

and conditions not visited due to time restrictions. A photo album and a comprehensive report on past field investigations and design and construction practices were provided to each delegate. The translated report is contained in Appendix E. Some of the photographs in the translation are of sites visited and are included in this report.

The Chinese seemed interested in heat- (thermal-)pipe designs, air ventilation systems, and other hybrid foundations, and in obtaining design data and reports on foam insulation. Some information was provided on these subjects during the visit and additional information will be forwarded. There appear to be several areas for innovative engineering through cooperation with U.S. specialists. We believe there is a potential here and that the possibility should be pursued actively. Areas or activities that could have potential use are:

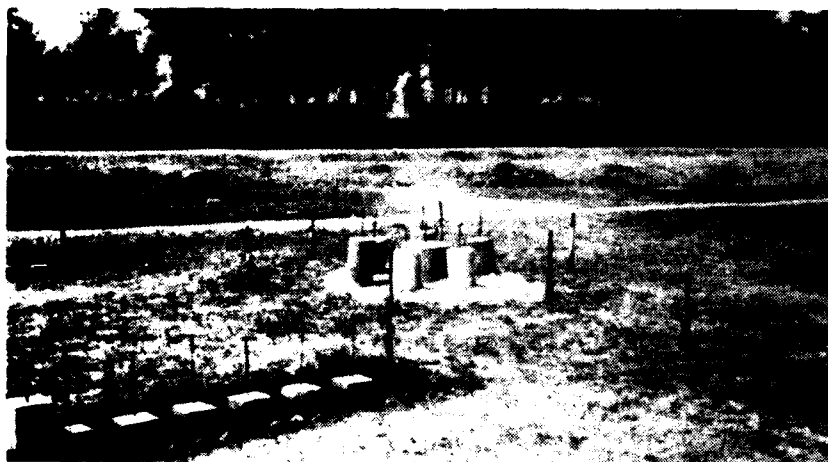


Figure 28. Wanjia Frozen Soil Field Test Station. Field installation to measure frost heave on piles and footings. (Lower: photograph no. 4806 by T.L. Péwé.)

1. Development of a general comprehensive design/construction manual including design procedures and quality control procedures.
2. Development and use of foam insulation, laminated foam/wood structural sections for walks, roofs, and floor systems.
3. Use of foamed-in-place insulation as a sealer around construction joints.
4. Use of slab foundations with controlled convective air circulation, thereby allowing a slab without piling.

Wanjia Frozen Soil Field Test Station, Heilongjiang Provincial  
Hydraulic Scientific Research Institute — 19 July, 1984

This site was established in 1979 to study frost-heave forces on various foundation elements. The site is located 19 km west of Harbin. Soils at the site are clayey silt (common to the surrounding areas) underlain by sand at depths between 6 and 7 m. Load frames and reaction piles were installed as unyielding references on 14 test plots. Water is controlled at the facility to allow saturated and unsaturated surface conditions to be considered. Site conditions include a frost depth of 150 to 165 cm, a freezing index of 1900°C-days and a mean annual temperature of +3.5°C.

Routine observations at the site consist of air, surface, and soil temperatures obtained from thermometers at depths of 40, 80, 120, and 160 cm. Frost tubes are used to measure frost penetration. Surface heave and heave over various depth increments are measured by heave plates and extension rods, referenced to wires stretched between nonheaving reference piles.

The pile heave test plots (Fig. 28 and 29) measure heaving forces on short piles of various diameters and lengths up to the maximum depth of frost penetration. Frost measurements are obtained from proving rings with dial indicators located between the pile tops and the load frames. Different test plots are used to evaluate the effects of pile diameter, pile groups, and different anti-heave measures such as roofing felts and greases. Reaction piles are of two types: exploded-tip steel pipes or bored-in, 12-m long piles. Details on both these reaction-pile types are unclear.

An additional set of test plots and four-pile reaction frames is used to measure heave forces on flat slabs with dimensions up to 3x3 m. Two small test plots are used to measure heave of different soil types.



Figure 29. Wanjia Frozen Soil Field Test Station.  
Field installation to measure frost heave on piles and footings.

Two test installations (Fig. 30) measure the lateral frost-heaving forces on short opposed retaining walls by means of strain gauges on steel strut-rods holding the walls against lateral heaving. Vibrating-wire, earth-pressure meters were also installed at these plots, and some temperature sensing by thermistors was apparent, although no details were given.

Two additional frost-heave test sites of this type are reportedly in existence in northeast China, located at Mangui and Chintao (see Fig. 1). Details of these sites were not available, but could be obtained from Guo Lin, Senior Railway Engineer, who accompanied us on the trip.

The frost-heave test site at Wanjia was an impressive field facility. Efforts should be made to obtain and distribute translations of reports on the significant test results from this site. Future exchanges would be enhanced by acquisition of additional temperature data to determine frost-depth changes around the test piles and pile groups.





a. Concrete structure instrumented to measure lateral frost forces.



b. Xie Yinqi, station director, holds a thermometer used to measure ground temperatures at various depths.

Figure 30. Wanjia Frozen Soil Field Test Station, 19 July 1984.

#### Heilongjiang Provincial Hydraulic Scientific Research Institute (Fig. 31)

Frozen-ground testing was started in the 1950's. The institute has 14 test sites throughout the province. Although not specifically stated, the total staff is probably about 150. A visit was made to the Hydraulic Engineering Laboratory, which had several flumes. A separate lab had a new cold box with controls between  $-20^{\circ}$  to  $-40^{\circ}\text{C}$ . The box contains four cylindrical test cells to which variable loads can be applied during freezing.

#### Heilongjiang Provincial Low-Temperature Construction Science Research Institute (Fig. 32)

Director Yuan Zhonghuai, who attended the Third Ground Freezing Conference in Hanover, welcomed and briefed the group. When Yuan reaches 65 this year, Li Xiongchuang will replace him. The institute has a staff of 160. There are three divisions: (1) Bases and Foundations, which includes frozen soil, (2) Structures, which includes design site work in

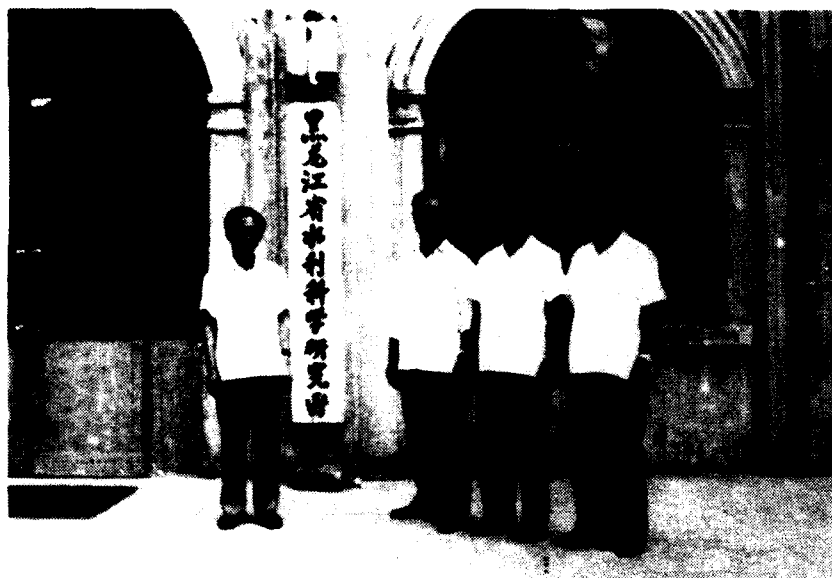


Figure 31. Group photograph in front of the Heilongjiang Provincial Hydraulic Scientific Research Institute, Harbin, 19 July 1984. Zhou Xingwu, director, is second from the left.



Figure 32. Group photograph in front of the Heilongjiang Provincial Low-Temperature Construction Science Research Institute, Harbin, 19 July 1984. Yuan Zhonghuai, director, third from left, and Li Xiongchuang, new director, fourth from left.

winter, and (3) Construction Materials, including local materials such as pumice. There are six coldrooms, with a 30 m<sup>3</sup> capacity. The institute has two field stations, one 10 km beyond the Wanjia station and the other in the Dacing area. There is no research on snow and ice since that is performed in Lanzhou. The coldrooms and labs are under renovation, which was scheduled for completion in late October 1984. Signs of the renovation were obvious from the large amounts of construction materials in the yard. A banquet was hosted in the institute dining room.

Yakeshi Forest Survey and Design Institute (Fig. 33)

This institute was founded in 1950 and in 30 years has become a comprehensive institute. There are 117 engineers and 300 technicians. The institute serves the Da Hinggan Ling and does planning and designing for forestry management. They are concerned with construction of roads, bridges, engineering geology, and water resources. The emphasis is on solving problems, but some research is performed that serves engineering needs. The delegation did not visit the institute; the technical meetings were held in the Yakeshi Guest House.

Yitulihe Frozen Ground Observation Station

This station belongs to the Yitulihe Railway Branch Administration of the Harbin Railway Administration (Fig. 20). The station was established in

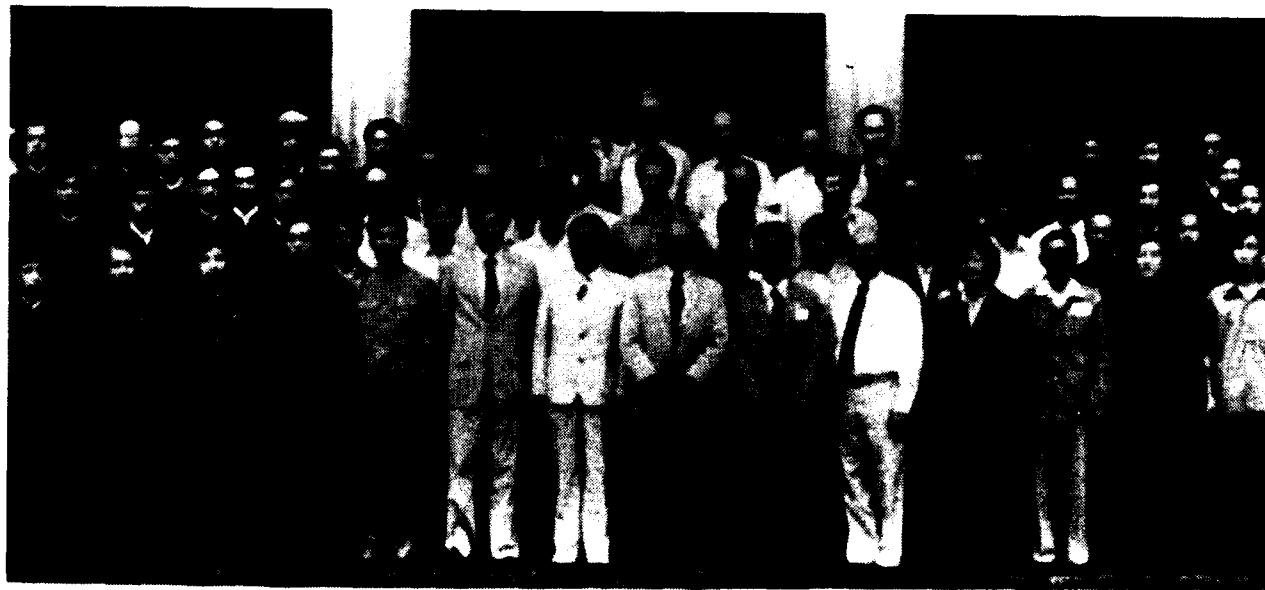


Figure 33. Group photograph in front of the Yakeshi Guest House, 21 July 1984. Han Xuchang, director, Yakeshi Forest Survey and Design Institute, is between Brown and Péwé. Xu Tiechuan, vice-director, is at Péwé's left.



Figure 34. Group photograph in front of the Low-Temperature Laboratory of the Qiqihar Research Institute of Science and Technology, 24 July 1984. The director of the institute, Miao Shiheng, is at Jerry Brown's right.

1978. There are 16 staff members. They design and monitor bridges and buildings. The director, Jia Mingchao, attended the Second National Permafrost Conference in 1981 (Brown and Yen, 1982).

#### Qiqihar Research Institute of Science and Technology

Miao Shiheng, director, briefed us at the institute's Low-Temperature Laboratory (Fig. 34). The Qiqihar Research Institute of Science and Technology was founded in 1958. It is a comprehensive research agency studying railway transportation, in which there are several research departments of railway transportation, locomotive and rolling stock, communication and signal, railway construction, metal, and chemistry. There is a total of 120 staff and workers, including three senior engineers and 49 engineers. Introductions included the chiefs of the Civil Construction Lab, Locomotive Research Lab, Metal and Chemical Research Lab, Frozen Ground Lab, and the Engineer of Coldrooms, Liu Zhen. They work mainly on research tasks given by the Ministry of Railways and the Harbin Railway Administration. Since it was established, the institute has completed over 110 projects that contributed to the development of railway transportation.

The low-temperature laboratory that we visited (Fig. 35) was built in 1967 to solve technical problems of transportation and production equipment in the severe-cold area and the permafrost region. It has three cold-test



Figure 35. Large coldroom used for low-temperature testing of materials at the Low-Temperature Laboratory, Qiqihar. Railcars are brought in on tracks in the floor. (Photograph by Larry Sweet.)

rooms, a material-test room, and a machine shop. The largest coldroom is 15 m long, 5.5 m wide, and 4.8 m high. There is a special railway track leading into it. Ammonia is used as the refrigerant; the pumps were fabricated in China. The temperature in the cold laboratory rooms can reach  $-50^{\circ}\text{C}$ . The laboratory has become one of the important bases of low-temperature tests of railway systems in the country.

## LANZHOU

### GENERAL DESCRIPTION OF VISITS AND EXCHANGES

After a visit to Xian, the delegation took the train to Lanzhou (Fig. 36). The rail line followed the Wei He gorge. The line was built in 1945 and reconstruction commenced in 1955 due to numerous landslides. It was electrified in 1980. As many as 100 tunnels were built through the rugged and scenic mountainous region.

We were hosted in Lanzhou by the Academia Sinica's Institute of Glaciology and Cryopedology (Fig. 37) and the Chinese Academy of Railway



a. One of many tunnels.



b. View of Wei He valley. (Photograph by Larry Sweet.)

Figure 36. Photographs of rail route between Xian and Lanzhou, 26 July 1984.

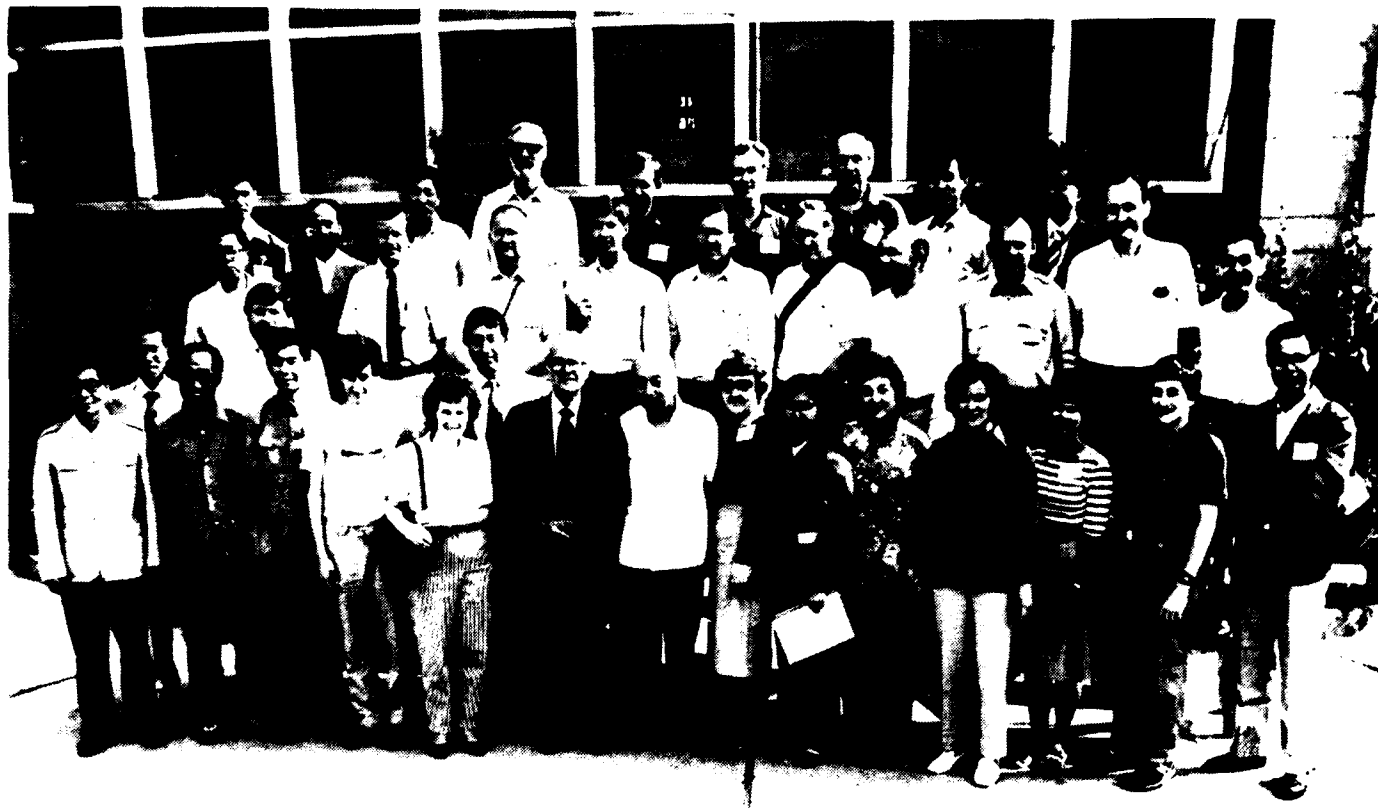


Figure 37. Delegation, family members, and members of the Lanzhou Institute of Glaciology and Cryopedology, 28 July 1984. Front row (left to right): Cheng Guodong, Zhu Yuanlin, Gao Renen, Ray Kreig, Zhou Hongye, Michael Brown, Celia Brown, Jerry Brown, Troy Péwé, Shi Yafeng, Betty Smith, Zhou Youwu, Jacqueline Manikian, Mrs. Cheng Guodong, Judy Smith, Kevin Brown, Chen Xiaobai. Second row: Zeng Qunzhu, Xie Zichu, Gunter Weller, Richard Reger, Stuart Rawlinson, Robert Smith, Richard Berg, Victor Manikian, Michael Metz, Oscar Ferrians, Gu Zhongwei. Third row: Xu Xiaozu, Tong Boliang, Larry Sweet, David Esch, Ted Vinson, George Gryc, Zhao Yuehai, Qiu Guoqing.

Sciences' Northwest Institute. A half day was spent at each institute in briefings and visits of the facilities (Table 9). Brown and Péwé had previously visited the institutes and were able to note changes. The second and final day was devoted to two concurrent sessions on general geocryology and engineering geocryology. All 15 U.S. delegates presented talks and there were five Chinese presentations. The talks were based on the list of topics the delegation had submitted in advance (Appendix B). Approximately 100 Chinese attended the two concurrent sessions. A number of discussions of frost heave, remote sensing, and piles and foundations took place. These intensive discussions resolved many questions regarding

Table 9. Schedule of U.S. Permafrost Delegation, Lanzhou

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28 JULY (SATURDAY)

6:00 a.m. Arrive Lanzhou by train.  
Transfer to Ning Wu Zhuang Hotel.

7:00 a.m. Breakfast

8:00-12:00 a.m. Visit to Institute of Glaciology and Cryopedology.

12:00 Lunch

2:30-6:30 p.m. Visit to Northwest Institute of Chinese Academy of Railway Sciences.

7:00 p.m. Banquet at dining room of Lanzhou Institute of Glaciology and Cryopedology.

29 JULY (SUNDAY)

Session I. General Geocryology (Meeting Room 227)

8:00-12:00 a.m. Chair: Shi Yafeng, T.L. Péwé

Shi Yafeng, J. Brown  
Introduction  
(Interpreter: Gao Renen)

R.L. Berg  
Surface temperature of roads and airfields in permafrost areas.  
(Interpreter: Xu Xiaozu)

R.A. Kreig  
Airphoto interpretation and computerized soil data banks used in terrain analyses of two 1300-km-long pipelines across Alaska. (Interpreter: Gao Renen)

Huang Yizhi  
A geophysical method for permafrost survey in China.  
(Interpreter: He Yixian)

S.E. Rawlinson  
Permafrost and related features in the Prudhoe Bay region Alaska.  
(Interpreter: Xu Xiaozu)

T.L. Péwé  
Distribution of past and present permafrost in mountainous regions of the United States.  
(Interpreter: Gao Renen)



3:00-6:00 p.m.

Chair: J. Brown, Zhou Youwu

O.J. Ferrians

Permafrost and related engineering problems in northern Alaska.

(Interpreter: Qiu Guoqing)

Ding Dewen

The relationship between geocryology and thermodynamics.

(Interpreter: Zan Tingquan)

G. Weller

The potential effects of the carbon dioxide global greenhouse on climate and permafrost.

(Interpreter: Yao Tandong)

R.D. Reger

Cryoplanation terraces of interior and western Alaska.

(Interpreter: Qiu Guoqing)

Session II. Engineering Geocryology (Meeting Room 203)

8:00-12:00 a.m.

Chair: Xie Zichu, T. Vinson

Chen Xiaobai

Moisture characteristics and frost heave of canals in cold regions.

D.C. Esch

Experimental insulated and fabric-reinforced embankments on permafrost

(Interpreter: Zhu Yuanlin)

G. Gryc

Construction and environmental considerations of drill pads and associated roads and airstrips, northern Alaska.

(Interpreter: Chen Xiaobai)

Yang Hairong

Selection of design principles for railways in permafrost areas.

(Interpreter: Zhu Qiang)

V. Manikian

Pile-driving and load-test experiments in permafrost.

(Interpreter: Zhu Yuanlin)

M.C. Metz

Long-term performance of structural and insulated work pads, Trans-Alaska Pipeline.

(Interpreter: Chen Xiaobai)

3:00-6:00 p.m.

Chair: D.C. Esch, Huang Xiaoming

R.E. Smith

Unacceptable settlement of piles in permafrost--remedial action and results.

(Interpreter: Zhu Yuanlin)

L. Sweet

Thermopipe installations to control thaw-settlements on roads and airfields on permafrost

(Interpreter: Zhu Qiang)

T. Vinson

The segregation potential and frost-heave susceptibility of soils.

(Interpreter: Chen Xiaobai)

6:30 p.m.

Banquet by Northwest Institute of Chinese Academy of Railway Sciences.

30 JULY (MONDAY)

9:30 a.m.

Depart hotel for airport.

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Chinese engineering geocryology, particularly on foundation design and frost-heave research.

#### PILE-SUPPORTED STRUCTURES ON PERMAFROST

The use of pile supported-foundations in northeast and western China was discussed in detail with Ding of the Northwest Institute. Specifically, the discussion centered on current pile-design criteria and testing in the U.S. and China. These discussions brought out one important fact: that currently available literature probably does not accurately reflect the current state of knowledge that the Chinese possess for pile design in permafrost conditions.

The Northwest Institute appears to have complete control of pile-design criteria, development, testing, and applications. This point was made twice in discussions with various institute members at the technical discussions and at the banquet held 29 July 1984.

Extensive pile testing in permafrost has been completed in both northeast and western China in the last 6 years. These tests appear to involve moderate- to long-term load testing (1 to 6 mo.) at various project sites. The pile-test apparatus and procedure appear to be very similar to those used in the U.S. A calculated load capacity is determined for each test pile. The first load is 10% of the calculated capacity. Each subsequent load increment is increased by 10% of the calculated capacity. Each load development appears to be held for at least 7 days. Data collected from these Chinese pile-load tests could be of value to U.S. engineers if the

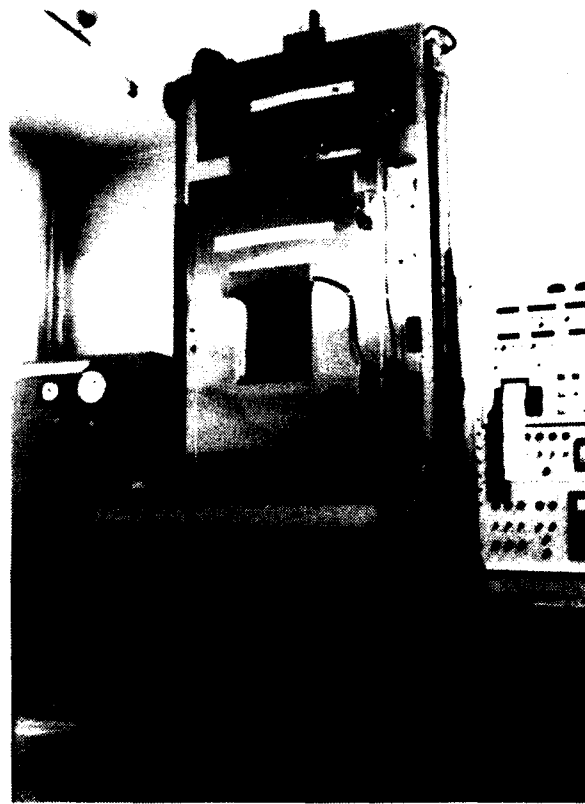


Figure 38. Controlled-environment chamber for material testing at the Northwest Institute, Lanzhou.

data contain sufficient details concerning soil properties, pile-construction procedures, temperatures, and time-deflection information.

It is apparent that the Chinese understand well the basis of permafrost pile design by the adfreeze method. They may be interested in recent advances made in pile design in Canada and the U.S. using the creep method. This point could be a basis for exchange of data.

Discussions with Ding indicated that the fill placement, which blocks air circulation around permafrost piles at Mangui in northeast China, is a problem related to education of local residents who fill in building perimeters to maintain warm floors during winter and to provide storage space beneath building floors. They are attempting to correct the problem to avoid long-term performance problems.

Time did not permit a detailed discussion of frost-heaving design for permafrost piles. There were indications, however, that near-surface soil characteristics (e.g. frost-heave susceptibility) were used with special design criteria to keep heaving forces to a minimum in pile design.

The adfreeze method of pile design is used to design pile length for a given load. The design temperatures used are those observed under natural conditions. It is assumed that elevation of the structure will result in no increase in ground temperatures. Ultimate adfreeze strengths have been determined for various temperature conditions. A factor of safety related to the type of structure is applied to the ultimate adfreeze strength. For railway work a factor of safety of 2.5 to 3.0 is common.

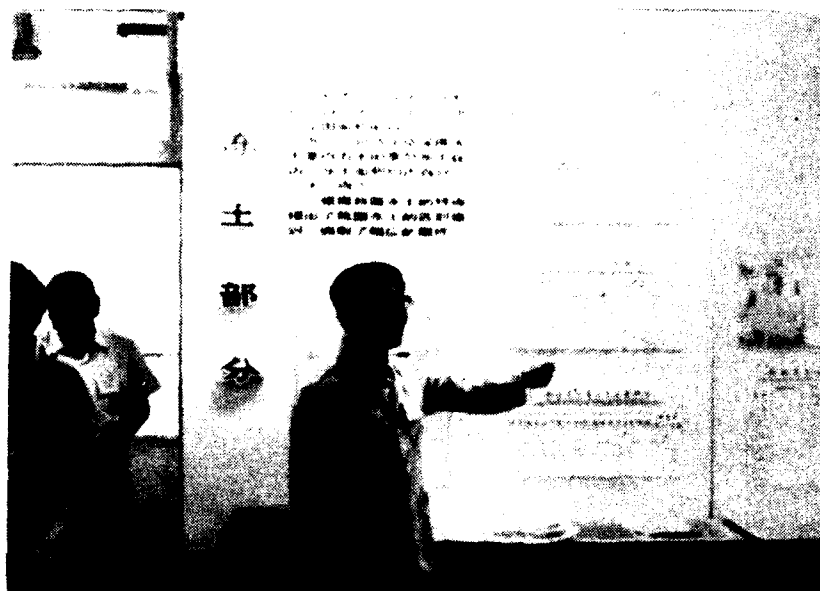
Our overall impression is that the Chinese are current on permafrost pile design but could benefit from our experience, especially with creep analysis, thermal piles, and use of steel piles.

#### EMBANKMENTS AND FROST HEAVE

According to discussions with various engineers and scientists in Lanzhou (primarily Zhu Qiang, Water Resources Department of Gansu Province, and Chen Xiaobai and Cheng Guodong, Lanzhou Institute of Glaciology and Cryopedology), frost heave is the major problem in seasonal-frost areas and thaw settlement is the major problem in permafrost areas (Fig. 39). The most significant frost-heave problems are related to irrigation canals and the worst thaw problems are associated with the new Qinghai-Xizang Highway, although some buildings, railroad embankments, and other structures also suffer.

Two types of laboratory frost-heave tests were observed at the Lanzhou Institute of Glaciology and Cryopedology; a frost-heave force test and a frost-heave ratio test (Fig. 40). The heave-force test was in progress. The entire device was in a coldroom. Air in the coldroom cooled the upper surface of the sample. It was 50 by 50 cm in plan and the sample was 20 cm thick. A circular plate with one-fifth the total surface area of the sample was placed in the center. A proving ring was attached to a rigid frame to measure the heave force. A 5-cm layer of sand was placed at the bottom of the test soil and the water table was maintained at the top of the sand. Results from these tests are used in the design of shallow foundations.

The heave-ratio test cabinet was large enough for four samples. Thermo-electric cooling was used to cool the air over the samples. One cooler served two samples and the coolers were cooled by tap water. Each heave cell is 20 cm high with a slight top-to-bottom taper. The inside diameter is 11 cm at the top and 10 cm at the bottom. A 5-cm layer of sand

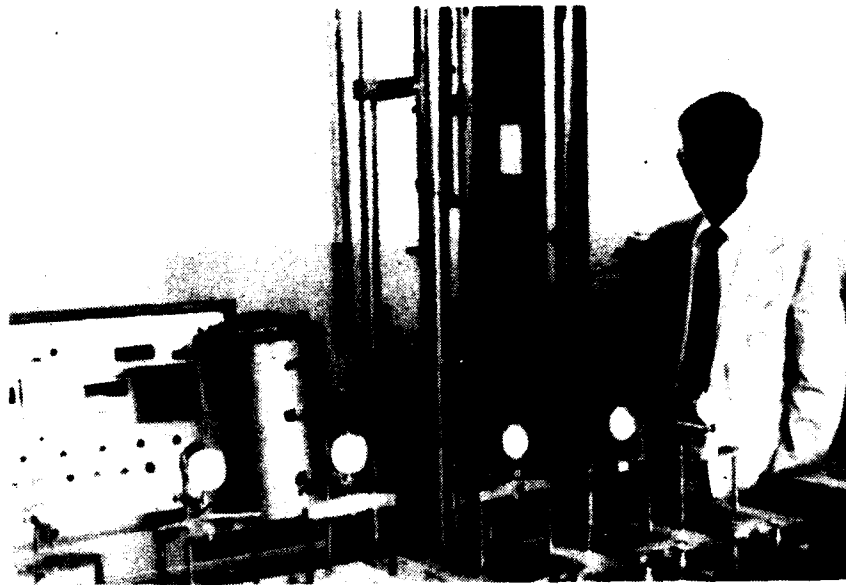


a. Cheng Guodong describes permafrost conditions in China. (Photograph by Larry Sweet.)



b. Test apparatus: one-dimensional soil-filled columns used to study soil moisture migration and capillary tension; description of test apparatus given by Chen Xiaobai.

Figure 39. Lanzhou Institute of Glaciology and Cryopedology, 23 July 1984.



a. Soil consolidation load frame; description given by Zhu Yuanlin.



b. Insulated cabinet inside cold room with frost-heave test cells. Conventional dial gauges, used to monitor the magnitude of heave, have been converted to provide electrical output.

Figure 40. Test apparatus at Institute of Glaciology and Cryopedology, 23 July 1984.

is at the bottom of the test soil. The water table is maintained at the top of the sand. Generally no surcharge is used, but surcharge can be applied. Thermocouples are used to monitor sample temperatures. They are connected to a data logger and micro-computer. Water influx into each

sample is controlled and monitored. Soils are normally saturated before the test is started. Information on the surface temperatures applied during a test, and the duration of the test was not indicated.

The Chinese were interested in the CRREL frost-heave model. The institute has recently started development of a numerical model of frost heave. Chen Xiaobai is determining moisture-characteristic curves and curves relating hydraulic conductivity and moisture content. He is also measuring (or attempting to measure) pore pressures in freezing and frozen soil columns in the laboratory. The columns are about 2 m long by 10 cm wide in cross section. A nonfreezing liquid was not used in the tensiometers.

Zhu Qiang and Chen are both very interested in working with us on frost-heave studies in the laboratory and field. Prior to our departure, Berg, Esch, Sweet, Vinson, Zhu, and Chen met for nearly 2 hours to discuss the formation of a joint study. The study could benefit from two years of data that have been collected from a site at Zhangye, about 500 km northwest of Lanzhou, where the Chinese have installed 23 test sections with four soil types: clay, clay loam, loam, and fine sand. Ground water is at 0.5, 1, 1.5, and 2.5 m for each soil type. The other seven sections are replications of these 16 sections. The Chinese monitor temperatures three times a day, frost heave two times a day, and take cores of the frozen soil every 20 days. Frost heave is measured at eight depths in nearly all of the test sections. The area receives very little snow; any accumulation of snow is removed. Precast concrete pavers are placed on the surface. Surface temperatures are monitored three times a day with mercury thermometers that are partially embedded in the concrete. The study will continue through 1988 or 1989. Chen is determining the hydraulic properties of the soils.

This data set would provide an excellent evaluation of the CRREL, segregation potential, and other frost-heave models. The Chinese are also conducting theoretical studies at Peking University, according to Chen. Their ideas may also provide other concepts of processes in the freezing zone.

An initial cooperative study involving Berg, Esch, Vinson, Chen, and Zhu is envisioned. As models are developed or refined, they may be applied to thaw-settlement and thaw-weakening situations in permafrost areas. In the near future, the Institute of Glaciology and Cryopedology plans to

expand a research station on the Xizang (Tibetan) Plateau. The Northwest Institute already has a field test site there. Thus, the Ministry of Railways could also be involved with the study.

Having developed and validated models on these or other test sites, both Chinese and U.S. engineers would have access to models for predicting frost heave or thaw settlement or both for engineering projects. Such predictions could save large amounts of maintenance funds for roads and railways. It is also possible that these models could be expanded or adapted to the design of piles and footings in seasonal-frost and permafrost areas.

#### LANZHOU INSTITUTES

Institute of Glaciology and Cryopedology, Academia Sinica\*  
Address: 14 Donggang West Road, Lanzhou, Gansu

Honorary Director: Shi Yafeng (Researcher)

Director: Xie Zichu (Associate Researcher)

Deputy Director: Zhou Youwu (Associate Professor)

#### Chronological events.

1958 - Established a prospecting unit called the Alpine Ice and Snow Utilization Team in Lanzhou under the Academia Sinica, which started investigations of alpine glaciers in northwest China.

1960 - Started investigations of permafrost on the Qinghai-Xizang Plateau.

1961 - Established the Tian Shan Glaciological Station.

1962 - Transformed into the Department of Glaciology and Geocryology under the Beijing Institute of Geography of the Academia Sinica, performing research in glaciology, geocryology, and hydrology of arid regions.

1964 - Participated in scientific investigations of the Xixabangma Peak district in the Himalaya Mountains, started investigations of frost hazards of the Da Hinggan Ling district in northeast China, and carried out research on glacial debris flow in the southeastern part of Xizang.

1965 - Amalgamated with the Department of Desert Research under the Beijing Institute of Geography of the Academia Sinica and formed the Lanzhou Institute of Glaciology, Geocryology and Desert Research, and started research on permafrost at the Muli Mining District in Qinghai Province.

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\*This material was taken from a brochure provided by the institute.



1966 - Started scientific investigations in the Mt. Qorolangma (Everest) district, and investigated the debris flow in Sichuan and Yunnan Provinces.

1967 - Resumed study of permafrost questions of the Qinghai-Xizang Plateau along Qinghai-Xizang Highway. Work at the Tian Shan Glaciological Station was suspended. Started research on prevention of snow hazards in Tian Shan Mountains, and established the Gongnas Station for Snow Research (now run by the Xingjiang Institute of Geography).

1969 - Started to study permafrost questions in the construction of Jiangcang Coal Mine at Reshui in Qinghai Province.

1970 - The Low Temperature Laboratory began to operate.

1972 - Started research on the prevention of frost hazards to railway constructions in northeast China.

- Research on ice-jamming on the Huang He (Yellow River).

- Research on the engineering geology of permafrost at the Tian Shan mountain regions along the railway in southern Xinjiang.

1973 - Started glaciological investigations on the Qinghai-Xizang Plateau.

1974 - Started investigations on glacial variations in the Batura of Karakorum and in the Qilian Mountains.

- Carried out a large-scale study of permafrost questions in railway constructions on the Qinghai-Xizang Plateau.

1978 - Separation of the Desert Research Department to form an independent institute and the formation of the Lanzhou Institute of Glaciology and Cryopedology of the Academia Sinica. Some of the research personnel involved in debris flow were transferred to the Chengdu Institute of Geography of the Academia Sinica. Participated in research work on prevention of frost hazards in hydraulic structures in northeast China.

1979 - Started glacial-inventory work in China in accordance with the standard specifications of the World Glacial Inventory. Started to study permafrost questions in the re-pavement of the road surface with asphalt on the Qinghai-Xizang Highway.

1980 - Resumed work at the Tian Shan Glaciological Station. Proceeded with investigations of glaciers and permafrost in the Altay Mountains.

1981 - Carried out research on permafrost questions in drilling by artificial freezing in Huainan and Huanbei districts of Anhui Province and investigated frozen ground in the Tian Shan mountains. For the first time

participated in investigations of the Antarctic ice cap. Cooperated with Japan in the investigation of glaciers in the Tian Shan. Cooperated with West Germany in the investigation of glaciers and permafrost in the north-eastern part of the Qinghai-Xizang Plateau.

1982 - Proceeded with investigations on glaciers, permafrost, and snow accumulation in the Hengduan Mountains. Carried out studies on debris flows along the Baoji-Chengdu Railway Line. Proceeded with the study of questions on the Quaternary glaciation in the eastern part of China. Went on to study the prevention of frost hazards to irrigation canals in the Hexi Corridor in Gansu and the effects of shallow foundations in the seasonally frozen district of Daqing in northeast China.

Important Achievements. China has extensive glaciers and permafrost: perennially frozen ground occupies about 20% of the total area, while seasonally frozen ground occupies about 70%; the area of alpine glaciers is 56,500 km<sup>2</sup> with a water storage of about 5000 km<sup>3</sup>, and the area of stable snow coverage is 1,900,000 km<sup>2</sup>. Seasonal ice is widely distributed in rivers and lakes of northeast, north, and northwest China as well as in the Bohai Sea area, greatly affecting and closely related to the formation and evolution of the natural landscape and environment and to economic activities in communication, hydroelectricity, industry, mining, agriculture, etc.

Since 1958, existing glaciers and the Quaternary glaciation in more than 10 mountain districts of Qilian Shan, Tian Shan, Himalaya, Karakorum, Altay Shan, Hengduan Shan, etc. have been investigated, a glacial inventory has been compiled, and the distribution, storage, types, and characteristics of ice and snow resources in China have been preliminarily determined. On the basis of such investigations, the patterns and types of glaciers in China have been suggested, and the ice formation, temperature characteristics, and developmental conditions of various types of glaciers have been explored. The formation, evolution, and forecasts of ice and snow meltwater in the mountainous regions have been analyzed and studied. The variation of the Batura Glacier in Karakorum has been successfully foretold. The debris flow at Guxiang, of an extremely large scale and seriously affecting the Sichuan-Xizang Highway, has been comprehensively investigated and carefully observed at fixed points, and proper preventive solutions have been put forward. Snow avalanches and snowdrifts on the highways in the west Tian Shan mountains have been studied in depth, and

effective ways of preventing them have been developed. The formation of river ice on the Huang He has been studied, remedied, and prevented, and the distribution of the seasonal snow cover in China has also been studied.

At the same time, permafrost in the Qinghai-Xizang Plateau, Tian Shan, Altay, and the Da and Xiao (Lesser) Hinggan Ling are being investigated; its distribution, formation, types, and characteristics preliminarily ascertained; and the three-dimensional regularity of high-altitude permafrost in zonation is revealed and the theory of the formation of thick-layered ground ice by regelation is expounded. In the research on protecting engineering construction from frost hazards, the thermal properties of freezing-thawing soil have been systematically studied, and methods for determining various thermal characteristics of unconsolidated and construction materials under different states of freezing and thawing have been improved, and a set of thermal parameters with practical value and usage was put into use. The mechanical properties of permafrost and the relationship between various influencing factors have been systematically studied both in the laboratory and in the field, suggesting a series of parameters and measuring methods. The distributive characteristics of stress in frozen soil have been preliminarily tested both indoors and on site, and a model of the distribution of horizontal stress under concentrated load has been obtained. The assessment of engineering geology in permafrost regions has been studied and the engineering classifications of permafrost have been suggested. In addition, research on the prevention of debris hazards in southwest and northwest China has been undertaken.

To satisfy the demand of glaciological and geocryological investigations, stereophotogrammetry and remote sensing techniques have found extensive application. A series of specialized observatory equipment, such as a high-accuracy quartz crystal thermometer, glacial telemetry system, steam driller, hot water driller, etc., have been made by Chinese technicians.

Due to the efforts of the past 25 years, a number of technical staff and pioneers in scientific research with sufficient technical knowledge, undaunted spirit in facing difficulties and hardship, and zealous hearts for their own profession have been trained and matured. Now the Institute claims a total staff of 364, among whom 235 are scientists or technicians of various specialities, including 15 of high rank and 117 of middle rank, comprising 12 research and technical divisions:

Glacial Resources and Environment Division  
Chief, Zhang Xiangsong

Applied Physics in Snow and Ice Division  
Chief, Huang Maohuan

Permafrost Forecast and Environmental Protection Division  
Chief, Cheng Guodong  
Deputy Chief, Huang Yizhi and Ding Dewen

Engineering Geocryology Division  
Chief, Wu Ziwang  
Deputy Chief, Zhu Yuanlin

Paleoglaciology and Ancient Periglacial Action Division  
Chief, Wang Jingtai

Tian Shan Comprehensive Glacial Experimental Station  
Deputy Chief, Wang Zhongxiang

Remote Sensing in Cold Regions Division  
Chief, Zeng Qunzhu

Instrumentation Division  
Chief, Wang Liangwei

Survey and Mapping Division  
Chief, Chen Jienming

Mass Analysis Division  
Chief, Qiu Guoqing  
Deputy Chief, Ding Yuanxi

Library and Technical Information Division  
Chief, Ding Yama

Editing and Publication Division  
Chief, Ren Binhui

#### List of Publications

1. Journal of Glaciology and Geocryology: Quarterly, edited jointly with the Branch Association of Glaciology and Geocryology of the Chinese Society of Geography. Started publication in 1979. So far 6 volumes and 2 numbers have been issued.

2. Annals of Lanzhou Institute of Glaciology and Geocryology of the Academia Sinica. Irregular; so far 5 issues have been published by the China Science Press.

3. Annual Report of the Tian Shan Glaciological Station; 2 issues published so far.

4. China Glacial Inventory: 2 issues published so far.

5. Reports, special works, and collections of articles for conferences:

- 1959 Investigation Report on Existing Glaciers in the Qilian Mountains. China Science Press.
- 1965 Investigation of Permafrost along the Qinghai-Xizang Highway. China Science Press.
- 1965 Glacial and Hydrological Research of the Urumqi River in Tian Shan. China Science Press.
- 1975 Reports on Scientific Investigations in the Qomolangma (Everest) Peak District (1966 - 1968). China Science Press.
1. Modern Glaciers and Geomorphology
  2. Climatology and Solar Radiation
  3. Quaternary Geology
- 1980 Investigations and Researches on Batura Glacier in Karakorum. China Science Press.
- 1980 Glaciers in China (Album). Shanghai Science and Technology Press.
- 1980 Proceedings of Symposium on Qinghai-Xizang (Tibetan) Plateau, Geological and Ecological Studies of Qinghai-Xizang Plateau, Vol. 1 and Vol. 2, China Science Press.
- 1982 Report on Scientific Investigations in Xixiabangma Peak District. China Science Press.
- 1982 Collections of Selected Articles for the Conference of Glaciology and Geocryology of the Chinese Society of Geography (Glaciology). China Science Press.
- 1982 Collection of Selected Articles for the Conference of Glaciology and Geocryology of the Chinese Society of Geography (Geocryology). China Science Press.
- 1982 Debris Flow in Gansu Province. Publishing House of People's Transportation.
- 1982 Sitzungsberichte und Mitteilungen der Braunschweigischen Wissenschaftlichen Gesellschaft, Sonderheft 6, Die 1. Chinesisch-deutsche Tibet-Expedition, 1981. Braunschweig-Symposium, 14-16. 4. 1982. Verlag Erich Goltze GmbH & Co. KG, Göttingen.
- 1983 Collections of Selected Articles for the Second National Conference on Permafrost. Jointly Sponsored by the Chinese Society of Geography and the Chinese Society of Civil Engineering. Gansu People's Press.
- 1983 Symposium on the Research of Permafrost of the Qinghai-Xizang Plateau. China Science Press.

## Northwest Institute, Chinese Academy of Railway Sciences

The following lists the main divisions and the staff of the Institute:

|                 |   |
|-----------------|---|
| Li Jia:         | Former Director, Professor, Advisor   |
| Huang Xiaoming: | Director, Engineer  |
| Duang Wenrong:  | Party Secretary   |
| Wang Gongxian:  | Vice Director, Engineer   |
| Tong Zhiquan:   | Vice Director, Engineer   |
| Wang Jiwu:      | Chairman of Workers' Union  |
| Song Rui:       | Vice Chief of Technical Committee, Engineer                                       |
| Ji Linawen:     | Chief of the Institute Office   |
| Yang Hairong:   | Chief of Permafrost Division, Engineer  |
| Din Jingkang:   | Vice Chief of Permafrost Division, Engineer                                       |
| Li Guoliang:    | Group Leader of Pile Foundations in Permafrost Division, Engineer                 |
| Lu Guangdai:    | Chief of Landslide Division, Senior Engineer                                      |
| Feng Lianchang: | Chief of Desert Division, Associate Researcher                                    |
| Ma Ji:          | Chief of Loess and Fissure Soil Division, Engineer                                |
| Guo Guoping:    | Vice Chief of Geophysical Exploration and Surveying Technology Division, Engineer |
| Jiang Zhichao:  | Chief of Central Test Laboratory, Engineer  |
| Ma Zhonglong:   | Vice Chief of Technical Information Division, Engineer                            |
| Lu Weidong:     | Vice Chief of Scientific Research and Planning Department Engineer                |
| Ma Yuansheng:   | Interpreter   |

The new director, Huang Xiaoming (Fig. 41), was a member of the delegation that visited Canada in 1975.

The following updated account is based partly on observations from a 1981 visit (Brown and Yen, 1982). The institute was established in 1961 and specializes in geologic-engineering investigation for the Ministry of Railways. There are 380 staff of which 160 are technical. The institute occupies a number of buildings and we toured several, observing mainly test laboratories and the coldroom facilities.

The Northwest Institute covers a wide range of geographic regions. Desert work includes problems of blowing sand, which buries railway tracks and requires techniques for removal. Plateau conditions at 5000 m above sea level include snow and permafrost problems, including the study of thermokarst. The loess problem involves stability and strength.



Figure 41. Farewell photograph at Lanzhou Airport, 30 July 1984. Members of both the Northwest Institute and the Institute of Glaciology and Cryopedology are present. The new director of the Northwest Institute, Huang Xiaoming, is in front, lower left, and its vice-director, Tong Zhequan, is in the center front.

The institute is divided into the five technical divisions: 1) Landslides, (2) Permafrost, (3) General Research Laboratory, (4) Central Test Laboratory, and (5) Library and Technical Information. The institute's major research topics are: (1) prevention of landslides, (2) prevention of sand hazards to railways, (3) railway construction in loess regions, (4) railway construction and maintenance in permafrost regions, (5) construction of roads in salt-lake regions, and (6) geophysical exploration and civil engineering surveying techniques.

More than 1000 landslide sites along the railroad have been investigated. Studies of landslide mechanics, residual strength, and antislides piles were conducted. A great number of studies were conducted concerning the development of technology for building railroads in permafrost regions. The subjects of these studies included foundation engineering on thick underground ice, application of insulation material on frozen soils, development of engineering designs for buildings, bridge sites, and foundations, determination of natural and artificial limits in building bridges and houses, and chemical means of preventing frost heaving.

With respect to the work on sand control for railway lines, studies were conducted on the mechanisms of sand transport, solidification of sand

mass by chemicals, and mechanical and general sand-prevention methods. As for railway construction in loess regions, slope stability of the road base and the bearing strength of the loess foundation have been studied. Studies for construction of railroads in the salt lake regions, using shallow-earthquake instrumentation to determine the upper limit of permafrost and employing electrical methods to explore the resources of underground water, were also undertaken. In the area of civil engineering surveying and measuring techniques, studies are being conducted on the variation of the soil water content of foundations, automatic recording of ground temperature, and laser holography to determine soil displacement under a concentrated or uniform load.

The Central Test Laboratory is divided into four sections: Physics, Mechanics, Chemical Analysis, and Mineral Analysis. In the physics laboratory, various physical-property indices, such as grain-size distribution, volumetric weight, specific gravity, water content, and plasticity of soils, are determined. This laboratory is equipped with various kinds of equipment, including specific gravity meters, electrical furnaces, and vacuum pumps. The mechanics laboratory determines the shear strength, compressive strength, and the coefficient of compressibility of soils using triaxial, vertical-shear, solidification, and universal test machines. In the chemical analysis laboratory, tests for determining salt content, water quality, and the amount of volatile components in soils have been conducted with various precision analytical balances, chemical analysis instruments, and flame photometers. The mineral analysis laboratory determines the principal mineral and chemical element contents with the use of a differential heat calorimeter, an X-ray diffractometer, a spectrometer and a new Varian Model 475 atomic absorption spectrophotometer (a scanning electron microscope and a new X-ray diffraction system were observed). In 1981 we were given several kilograms of loess on which the CRREL labs conducted unfrozen water content and thermal measurements for comparison with the institute data (Tice, Zhu and Oliphant, 1984).

Most of the instruments are Chinese-made, and though some are quite old and others are very recently manufactured, they all seem to be in good working order. The experiment that impressed us most was the use of a laser to determine the strength field of the soil affected by an embedded pile. The landslide-testing setup includes a ring-type shear-test



apparatus, which is Chinese-made, and is used to predict conditions of landslides and soil residual strengths. The pile-stability test apparatus involves a 3-day duration and measures deflection along the pile shaft, moment around the pile, and the pressure strength. This institute has pioneered research on slope stabilization employing 10- to 20-m long reinforced concrete piles.

The Northwest Institute has a 3-storey coldroom facility. The basement contains the refrigeration system, which includes five compressors with Freon-2 as the working medium. After it is compressed, Freon-2 is cooled through a heat exchanger and becomes a low temperature and pressure liquid, which is subsequently passed through boxes containing  $\text{CaCl}_2$  solution. During this process, liquid Freon-2 absorbs heat from the  $\text{CaCl}_2$  solution, and once again becomes gas and is recycled to the compressor. The cooled  $\text{CaCl}_2$  solution is pumped to the air-chiller in the coldrooms and is also recycled. The temperature in the coldrooms can be lowered to  $-50^\circ\text{C}$ . The first floor of the facility houses four coldrooms of identical size (6 by 9 m) and is surrounded by an insulated outer corridor. An overhead hoist to the coldrooms is capable of moving large carts of prepared samples and large-scale model tests. All wires from the test samples lead out of the coldrooms to a central data collection room on the third floor. The third floor also contains the control room equipped with a large instrument-display panel for remote control of operations and monitoring the coldroom complex; the coldrooms can be maintained at a given temperature  $\pm 0.5^\circ\text{C}$ .

Our overall impression of the Northwest Institute is that it is well-equipped, it has some excellent geotechnical people who are highly motivated, and it conducts both basic and applied investigations.

Although we have been provided many "preprints" of papers in the past, few appear to be in readily published form. Apparently a great deal of information is contained in institute files and is not easily accessible. The following is a partial subject listing of unpublished information:

1. Prevention of landslides
2. Collected works on landslides
3. Road design and construction over deep ground ice
4. Determination of the railroad embankment critical height in the permafrost region of Qinghai-Xizang Plateau
5. Calculations of depth of thaw for tunnel foundations in permafrost

6. Determination of the upper limit of an empirical formula for the tunnel foundations in the permafrost regions of the Qinghai-Xizang Plateau
7. Design of various types of foundations for roadway structures in permafrost
8. Basic studies in using explosives for pile foundations in the permafrost regions of the Qinghai-Xizang Plateau
9. Testing of anchors (in plate form) in frozen soil
10. Long-term study of the withdrawal resistance of anchor rods in permafrost
11. Geological problems of road construction in the permafrost regions of the Qinghai-Xizang Plateau
12. Large-scale vertical-cutting field tests in thawed and thawed-frozen soil interfaces
13. Field testing of tangential heave forces
14. Studies of horizontal heave force
15. Development of methods for determining the permafrost table and its application in road building engineering
16. Methods for calculating permafrost tables
17. Variations of the artificial permafrost table of road embankments in the permafrost regions of the Qinghai-Xizang Plateau
18. Bearing capacity of concrete piles in permafrost
19. Permafrost tables after the construction of bridge foundations in the permafrost regions of the Qinghai-Xizang Plateau
20. Determination of an empirical formula for calculating the thickness of an insulating layer for road construction in the permafrost regions of the Qinghai-Xizang Plateau.
21. Minimizing tangential heave force with physical and chemical methods.

Institute of Plateau Atmospheric Physics, Academia Sinica

Brown and Weller met briefly with several members of this Institute just before their departure. Present were Professor Gao Youxi, honorary director; Cai Qiming, director; and Qian Yongfu. The institute has a staff of 230, of whom 50 are researchers. There are four major divisions; in order of size they are (1) Numerical Modeling and Prediction, (2) Atmospheric Physics, (3) Plateau Climatology and Meteorology, and (4) Boundary Layer and Energy Balance. Numerical modeling has three groups: large-scale processes such as monsoons, local or mesoscale, and synoptic meteorology. It has a Hungarian computer and plans to acquire a VAX 780 next year. They run GCMs (global climate models) with a grid size the same as MONEX covering the Northern Hemisphere from the equator to 80°N. Their

models are evaluating the effect of the Tibetan Plateau on atmospheric circulation over China. The Plateau Division is involved in long-term investigations, heat balance, and boundary-layer properties. It has four sites at which energy balance is being measured; and there is a joint project with Elmar Reiter of Colorado State University. The Atmospheric Division is involved with hail growth, atmospheric-electricity measurements on the ground at a station 300 km from Lanzhou, and cloud physics research using two 3-cm radars and microwaves.

#### FUTURE EXCHANGES

Our visit to northeast China, the Institute of Glaciology and Cryopedology, and the Northwest Institute should prove beneficial to the development of future exchanges on frozen ground. These contacts between the 15 U.S. delegates and their Chinese counterparts have increased the possibility of cooperative efforts. All institutes and administrative offices visited were enthusiastic about future exchanges. The Chinese Academy of Railway Sciences (CARS) seems more interested in a formal agreement than in the past. This point was reinforced when Brown met informally with Cheng Qingguo, the CARS president, in Washington, D.C., in late August 1984.

Frozen-ground activities in both the U.S. and China transcend traditional channels in agencies and academies. In China, major interests are in the Academia Sinica, the Ministry of Railways, and several provincial administrations. In the U.S., there is no single agency, institution, or constituency that has responsibility for all aspects of frozen-ground research and engineering. The Committee on Permafrost of the National Research Council has sought broad scientific and engineering participation -- a multidisciplinary approach that needs to continue.

The Chinese have operated in their frozen-ground areas essentially as we have in Alaska. While there are no large oil pipelines or oil fields in their permafrost regions, they do have operating road and rail systems and an active forest industry. They are addressing the task of modernizing their transportation systems and are concerned with problems related to environmental protection. They appear to be staffing their frozen-ground institutes for a concentrated effort in the next several decades.

At the Lanzhou Institute of Glaciology and Cryopedology, Brown was asked if the U.S. would be interested in developing a long-term program or

expedition covering permafrost, glaciology, and related fields at the newly proposed plateau field station and areas along the Qinghai-Xizang Highway. U.S. scientists and engineers were also invited to publish papers in English in the Journal of Glaciology and Cryopedology.

The Chinese will be active in studying and developing their resources and transportation and communication systems in frozen-ground areas. Their government and ours are encouraging the scientific and technologic communities to participate in mutually beneficial programs. U.S. scientists and engineers should actively pursue these opportunities. There is a significant core of knowledgeable scientists and engineers in China. The U.S. should maintain not only an awareness of the Chinese efforts, but should look for and undertake mutually beneficial study efforts. We should also encourage the commercial export of U.S. arctic engineering and products, many of which are technologies developed during oil exploration and production in Alaska.

The following topics were suggested by the U.S. delegation as the basis for joint U.S.-P.R.C. cooperative projects in frozen-ground research and engineering.

#### GENERAL GEOCRYOLOGY

(1) Establish several U.S. and Chinese ground-temperature sites using comparative instrumentation. To ensure comparable ground-temperature data, we agreed it was important to establish several sites in China and Alaska where Chinese thermometer strings and U.S. thermistors in liquid-filled PVC pipes and metal pipes could be installed and read for several years. This would provide the comparable mean annual ground temperature measurements required for engineering design, permafrost classification, and other temperature-dependent needs.

(2) Correlate landscape analysis and surveying techniques for permafrost terrain (permafrost mapping). Both countries have developed techniques of mapping permafrost conditions using borehole data and other surveying techniques. Chinese ground data combined with U.S. terrain-unit mapping could be a valuable asset to further understanding of the relationships of vegetation, substrate, aspect and slope, and climate to permafrost distribution. Our understanding of similarities and differences in permafrost conditions between the two countries would be improved.

(3) Conduct joint studies on ground ice and seasonal-icing formations. Both sides have experienced considerable maintenance problems due to formation of seasonal icings along roadbeds. Some solutions have been found in both countries. Exchanges of field experiences and solutions will be mutually beneficial. The study of all forms of ground ice and particularly that associated with pingos, palsas, and secondary ice segregation are of great interest. Understanding of these natural occurrences will be facilitated by joint field and laboratory studies in both countries. Of particular interest to the U.S. are ground ice forms encountered on the Qinghai-Xizang Plateau.

(4) Conduct joint studies on age, history, and climatic sensitivity of permafrost. The development and disappearance of permafrost during the climatic changes encountered throughout the Pleistocene and Holocene have been the topic of much speculation and field studies of periglacial features and current ground-temperature measurements. Interpretations obtained in the U.S. or China may be applicable under comparable conditions in the other country. We need to increase our ability to interpret evidence of climatic change and apply this understanding to future potential changes in permafrost terrain. The Chinese have many centuries of climatic data to aid such interpretations. Both countries can gain from such mutual exchanges of information.

(5) Evaluate and apply methods of environmental protection for permafrost terrain. The U.S. has considerable experience in analyzing potential impacts and methods for mitigating and restoring impacts. Some of these techniques can be transferred to the Chinese to help protect their unique environments. At the same time, the U.S. would benefit by observing how such procedures respond under conditions not normally encountered in the U.S.

(6) Conduct joint studies on origin and classification of alpine permafrost. The Chinese have considerable experience in classifying, mapping, and characterizing permafrost in mountainous areas. These studies are not well advanced in the U.S., partly because of limited ground-temperature measurements and subsurface data. We can benefit considerably by learning more about Chinese alpine-permafrost investigations.

## ENGINEERING GEOCRYOLOGY

(1) Utilize Chinese frost-heave field test facilities and U.S. laboratory and analytical capabilities to improve engineering practices. This activity would involve collecting frost-heave performance data for foundations, canals, and roadways at Chinese field-test facilities for use in a combined laboratory and analytical program to predict ice segregation and frost heave. The Chinese field test facilities are presently operational. Both the U.S. and the Chinese have laboratory and analytical techniques to assess and predict frost-heave phenomena that must be validated with field-test performance data. The reliability and accuracy of several predictive methodologies would be assessed under the project.

(2) Evaluate U.S. mitigative techniques (thermopiles, insulation) at Chinese field-test facilities to reduce permafrost and frost-heave degradation of foundations, piles, bridges, and roadbeds. The U.S. has considerable field experience in the use of insulations and thermopiles to prevent ground thaw. U.S. engineers and manufacturers of insulation and thermal devices are interested in evaluating mitigative techniques under Chinese construction and maintenance conditions. These activities would have commercial benefit to the U.S. and performance benefits to the Chinese.

(3) Prepare a comparative evaluation of U.S. and Chinese cold regions engineering design practices (based on available and revised building codes). Both the U.S. and China have design manuals and documented practices for construction on seasonally and perennially frozen ground. Comparison and synthesis of these procedures into improved practices will be mutually beneficial.

Although many, if not all, of these topics are focused on bilateral agreements, the knowledge gained would be applicable to similar activities with other countries involved in frozen ground research and engineering, particularly the U.S.S.R., Canada, Norway, and Japan. The U.S.-P.R.C. focus will enhance other multinational activities.

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APPENDIX A: PARTIAL LIST OF PARTICIPANTS AND DESCRIPTION  
OF OTHER INSTITUTES

ACADEMIA SINICA, BEIJING

Zhu Yonghang, Deputy Director, Foreign Affairs Bureau  
Zhing Liping, Geography Department

Institute of Remote Sensing Applications  
Yang Shiren, Director

ACADEMIA SINICA, HARBIN

Xu Xiangwen, Associate Professor, Institute of Engineering Mechanics  
Men Fulu, Head, Soil Dynamics Division

Lanzhou Institute of Glaciology and Cryopedology (see text and tables  
for participants and chiefs of major organizational elements)

MINISTRY OF RAILWAYS, BEIJING

Foreign Affairs Bureau  
Sun Yuxian, Director  
Li Mingde, Deputy Chief  
Chen Jiyan, Chief, International Cooperation Department  
Ye Jianjun  
Zhao Yuehai, Interpreter

Chinese Academy of Railway Sciences (CARS)

Zhou Hongye, Vice President  
Yen Zhenyuan, Engineer and Interpreter

Northwest Institute, Chinese Academy of Railway Sciences, Lanzhou  
(see text and tables for participants and chiefs of major  
organizational elements)

Publishing House

Li Yusheng, Vice President (formerly V.P. CARS)

Science and Technical Bureau

Gu Yechuan, Deputy Director

Transportation Division

Li Jiagu, Deputy Director

Bureau of Science and Technology

Luo Wenfeng

Special Design Institute

Zeng Kuising, Vice Chief Engineer  
Yang Chenzhi, Consulting Advisory Committee

Yi He Consulting Company (prior to 31 July, 1984, this was the Aerial  
Survey Department)

Wui Shiyuan, President  
Long Uchan, Vice President

Zhuo Baoxi, Chief Engineer  
Hu Ziguel - Aerotriangulation (interpreted)

**HARBIN RAILWAY ADMINISTRATION, HARBIN**

Guo Lin, Chief Engineer  
Lui Fengnian, Deputy Chief Engineer  
Li Chengmeng, Engineer, Science & Technology Office  
Shi Keli, Secretary  
Wang Lihua, Associate Chief Engineer  
Li Xiyan, Business Manager, TDJ System Research Center  
Yu Qingzhen, Engineer  
Zheng Qingjiang, Engineer  
Zhang Anqun, Engineer

**Qiqihar Branch**

Miao Shiheng, Director, Science & Technology Institute  
Li Qixiu, Engineer  
Liu Zhen, Engineer, Cold Storage Lab  
Yuan Tanji

**Yitulihe Branch - Frozen Ground Observation Station**

Jia Mingchao, Director  
Kang Ruiqing, Chief Engineer

**HEILONGJIANG PROVINCIAL GOVERNMENT**

**Hydraulic Scientific Research Institute, Harbin**

Zhou Xingwu, Director, Engineer  
Zhao Jinghui, Vice Director  
Xie Yingi, Director, Civil Engineering Research Department  
Wang Jianguo, Engineer  
Cheu Xianzi, Engineer  
Chui Tieling, Engineer  
Yu Peifang, Engineer  
Hong Yuwei, Engineer  
Gong Wanmin, Engineer  
Xu Zhenhai, Engineer

**Low-Temperature Construction Research Institute, Harbin**

Yuan Zhonghuai, Director, Chief Engineer  
Wang Lihua, Associate Chief Engineer  
Li Xiongchuang, Vice Director, Engineer  
Liu Hongxu, Engineer  
Jin Changcheng, Engineer  
Wang Gongchan, Engineer

**YAKESHI FOREST SURVEY AND DESIGN INSTITUTE**

Han Xuchang, Director and Engineer  
Xu Tiechuan, Vice Director and Engineer  
Fei Xieqing, Chief Engineer  
Gu June, Vice Chief Engineer  
Lu Guowei, Vice Chief Engineer  
Wu Xianlu, Vice Chief Engineer  
Wen Peisheng, Vice Chief Engineer  
Wang Fubin, Director Engineer  
Teng Jiajun, Director Engineer

Wu Liji, Director Engineer  
Zhao Lianzhong, Director Engineer  
Han Wenhui, Director Engineer  
Wen Binglin, Director Engineer  
Zhou Yuchun, Director Engineer  
Liu Changshan, Director Engineer

Chief, Forest Management Administration  
Chairman, People's Congress  
Gai Gulatu, Mayor of Yakeshi  
Yang Fumao, Deputy Director, Foreign Affairs Office, Hulun Buir

Institute of Remote Sensing Applications, Academia Sinica, Beijing

A brief visit was made to the Institute by Brown and Kreig. The director, Yang Shiren, briefed us. The institute was formed in late 1979 with personnel from the Institute of Geography. Because the institute is well-known to many remote sensing specialists in the United States, only a very short summary is included. There is a total staff of 230. The institute has six laboratories: (1) Special measurements, (2) Digital image processing, (3) Remote sensing image analysis, (4) Cartography, (5) Joint information system, and (6) Airborne remote sensing. There are three separate modern computer and image-processing systems available for processing U.S. Landsat multispectral data tapes. Our discussions focused on use of enhanced Landsat products in conjunction with conventional remote sensing and ground truth. A major new emphasis is on Landsat mapping of the Xizang (Tibetan) Plateau and Lhasa. Satellite imagery will need to be used for land-cover mapping, as the 1,200,000 km<sup>2</sup> region is too large for conventional aerial photography. Ground-truth data will be minimal. A six-person field team was currently at Lhasa to begin the work. Director Yang welcomed U.S. involvement. He is also interested in having his post-graduate (Ph.D.-level) people work in our institutions. There are currently eight people in the United States (6 Ph.D. candidates and two scholars). We met briefly with Yan Shouyong, who had returned a year ago from a two-year stay at Cornell.

The institute is currently housed in several buildings and in the main building with the Institute of Geography and Institute of Genetics. There are plans for a new building for the Remote Sensing Institute. However, acquisition of the land and relocation of the farmers has been an obstacle. We saw a publication entitled Airborne Remote Sensing of China that is scheduled for distribution in late 1984 and will be most valuable to U.S. scientists.

Special Design Institute, Ministry of Railways, Beijing  
Aerial Survey Department (as of 1 August, 1984, reorganized into the Yi He Consulting Company)

Following the official visit of the delegation, Kreig remained in Beijing for several days of lecturing and discussions with the Special Design Institute of the Railway Ministry in Beijing. Discussions focused on use of remote sensing for permafrost mapping and terrain analysis for route selection and the design of engineering projects.

The institute has several departments of which the Aerial Survey Department is one. It has just been reorganized into a consulting company, still owned by the Ministry of Railways, but now it is able to do work and projects for other ministries and companies (not permitted before).

Kreig was presented a Landsat atlas of China and an album containing 21 airphoto stereopairs of permafrost and glacial landforms in Xizang (Tibet).

APPENDIX B: TOPICS SUBMITTED FOR PRESENTATION BY THE U.S. DELEGATES

Richard Berg

Water movement in freezing and thawing soils  
Surface temperatures of roads and airfields in permafrost areas

Jerry Brown

Environmental planning and protection in permafrost regions

David Esch

Experimental insulated and fabric-reinforced embankments on permafrost  
Noncontact geophysical sensing of ground ice and temperature monitoring of permafrost

Oscar Ferrians

Permafrost and related engineering problems in northern Alaska  
The trans-Alaska oil pipeline and permafrost: A general description

George Gryc

Construction and environmental considerations of drill pads and associated roads and airstrips, northern Alaska  
Operation and maintenance of the Barrow gas field and related construction

Ray Kreig

Airphoto interpretation and computerized soil data banks used in terrain analyses for two 1300-km long pipelines across Alaska  
The landform approach to terrain analysis for natural resource inventory, geotechnical investigations and permafrost mapping in Alaska

Victor Manikian\*

Civil engineering solutions to oil production projects, Prudhoe Bay region, Alaska  
Pile driving and load test experiments in permafrost  
Construction and drainage in and over ice-rich frozen ground

Michael Metz

Long-term performance of structural and insulated work pads, trans-Alaska pipeline  
Effects of increased snow drifting on permafrost design temperatures

Troy Péwé

Distribution of past and present permafrost in mountainous regions of the United States

Stuart Rawlinson

Coastal stability in a permafrost environment  
Permafrost and related features in the Prudhoe Bay region, Alaska

Richard Reger

Cryoplanation terraces of interior and western Alaska

\*Manuscripts available from author: P.O. Box 100360, Anchorage, AK 99510.

Robert Smith

Design of closely spaced, warm production wells for ice-rich permafrost conditions

Unacceptable settlement of piles in permafrost: Remedial action and results

Larry Sweet

Thermopipe installations to control thaw settlements on roads and airfields on permafrost

Ted Vinson

The segregation potential and frost heave susceptibility of soils

Use of geotextiles in cold regions engineering

Gunter Weller

The potential effects of the carbon dioxide global greenhouse on climate and permafrost

Microclimates of permafrost landscapes of arctic tundra

|              |   |             |
|--------------|---|-------------|
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ENGINEERING LAB HANOVER NH J BROWN JUN 85  
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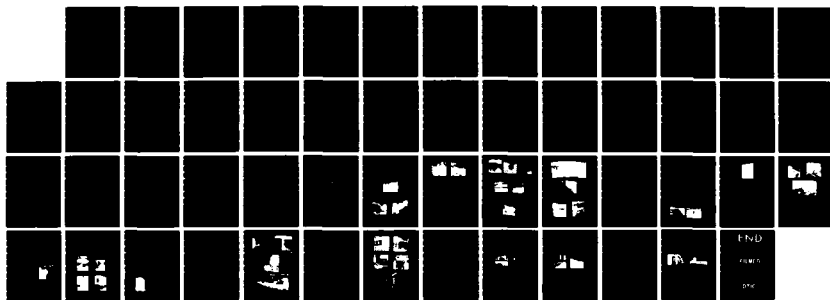
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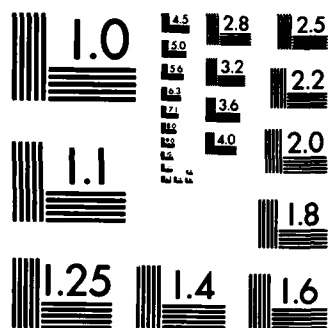
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MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A



APPENDIX C: PARTICIPATION OF THE PEOPLE'S REPUBLIC OF CHINA IN THE  
FOURTH INTERNATIONAL CONFERENCE ON PERMAFROST AND RELATED ACTIVITIES,  
JULY 1983

Jerry Brown  
(September 1983)

Introduction

The Fourth International Conference on Permafrost was held at the University of Alaska in Fairbanks 17-22 July, 1983. The Conference offered the opportunity for a large group of frozen-ground specialists from the People's Republic of China to visit the United States. Before this, the only other visits had been to Canada and several individual visits to the P.R.C. by U.S. scientists and engineers.\* In anticipation of increasing contacts with the various ministries and institutions in the P.R.C., the conference offered the opportunity to provide additional technical exchanges between the U.S. and P.R.C. participants. The U.S. organizers arranged special excursions and visits for the Chinese not only in Alaska but on the West Coast and elsewhere in the "Lower 48." Some of the private funds raised by the University of Alaska Foundation for the conference were both solicited for and expended to host members of the Chinese group while in Alaska.

This short report documents the activities of the Chinese and other individuals involved. It is intended to inform those who participated in the visits of the scope of the activities and to serve as a reference point for future exchanges, particularly visits to the PRC in the next year or so.

Chinese Participation

Prior to the conference, the Chinese submitted 40 papers for publication in the conference proceedings. The titles of the papers are listed in Table C5. Abstracts of these papers were published in the program and abstract volume, and the actual papers were published in the proceedings volume.

In all, 20 Chinese attended the conference (Table C1). Those Chinese authors who were in attendance formally presented their papers. Three of the 20 were scientists from the Lanzhou Institute of Glaciology and Cryopedology who were already in the U.S., two at CRREL and one at the University of Alaska. An official Railway delegation of 10, headed by Li Yusheng, vice president, Academy of Railway Sciences, was composed of engineers and scientists from the Ministries of Railways and Communication and the Academia Sinica. A second group of three represented water resource agencies.

\*Brown, Jerry, and Y.-C. Yen, 1982, The Second National Chinese Conference on Permafrost, Lanzhou, China, 12-18 October 1981. CRREL Special Report 82-3.

### Agenda

The 17 visiting Chinese arrived early so they could participate in pre-conference field trips. The 10 members of the official Chinese Railway delegation arrived in Anchorage on 12 July. They participated in an Alaska Railroad special Hirail trip to Whittier and a pre-conference rail tour to Fairbanks. The other group of seven arrived directly from China on 10 July and proceeded to Fairbanks for the pre-conference field trip from Fairbanks to Prudhoe Bay.\*

Following the 17-22 July conference in Fairbanks, the Railway delegation split into three groups for post-conference field trips. They reassembled in Anchorage on 27 July and went on to visit locations in Washington, Oregon, and California. They returned to China on 4 August.

The water resources group of three left Alaska immediately after the conference to visit West Coast sites and institutions. Shi Yafeng, director of the Lanzhou Institute of Glaciology and Cryopedology and deputy chief of the Academia Sinica's Earth Sciences Section, participated in the conference as a co-chairman of the entire delegation. Following the conference, he visited and lectured at a number of institutions. After the post-conference field trip from Fairbanks to Anchorage, Cheng Guodong and Liu Hongxu returned directly to China, and Cui Zhijiu visited Washington, D.C. and CRREL and Dartmouth College in Hanover, N.H.

Figure C1 is a route map for the various field trips. The following individuals participated on these trips:

| <u>A-1 and West Coast Trip</u> | <u>Pre-Conference A-2</u> | <u>Post-Conference A-2</u> | <u>B-4</u>    | <u>B-6</u>   |
|--------------------------------|---------------------------|----------------------------|---------------|--------------|
| Li Yusheng                     | Shi Yafeng                | Li Yusheng                 | Shi Yafeng    | Chen Xiaobai |
| Chen Guojing                   | Cheng Guodong             | Chen Guojing               | Cheng Guodong | Lu Guowei    |
| Chen Xiaobai                   | Cui Zhijiu                | Cui Chenghan               | Cui Zhijiu    |              |
| Cui Chenghan                   | Liu Hongxu                | Ding Jingkan               | Qiu Guoqing   |              |
| Ding Jingkan                   | Wang Liang                | Wang Hong                  | Zhou Youwu    |              |
| Lu Guowei                      | Xu Bomeng                 | Zhao Yuehai                |               |              |
| Wang Hong                      | Zhu Qiang                 | Zhao Yunlong               |               |              |
| Zhao Yuehai                    |                           |                            |               |              |
| Zhao Yunlong                   |                           |                            |               |              |
| Zhou Youwu                     |                           |                            |               |              |

Tables C2, C3, and C4 summarize the major points in the various itineraries.

\*Brown, J. and R.A. Kreig, 1983, Guidebook to permafrost and related features along the Elliott and Dalton Highways, Fox to Prudhoe Bay, Alaska. Guidebook 4, Alaska Division of Geological and Geophysical Surveys, Fairbanks, Alaska.

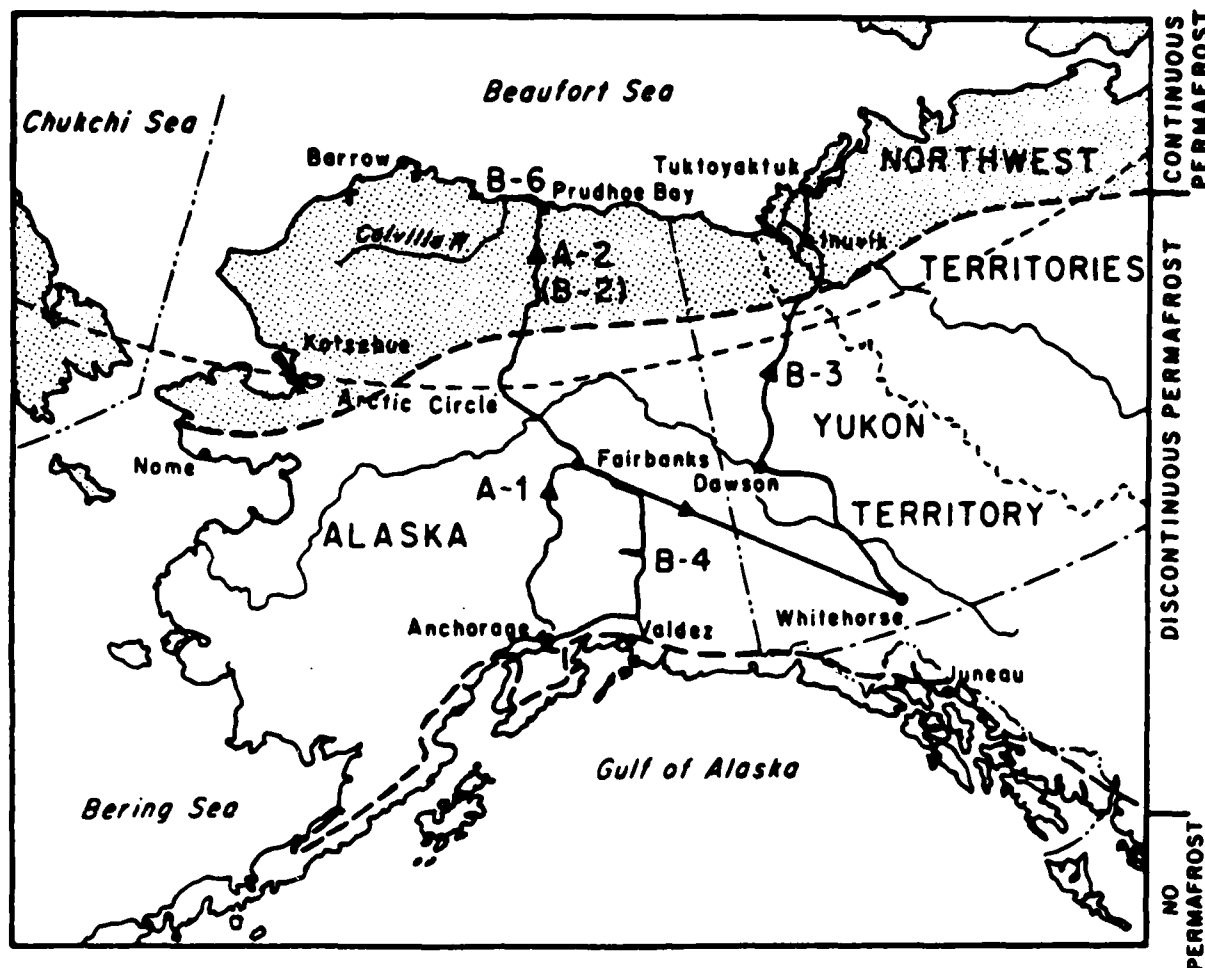


Figure C1. Route of field trips, Fourth International Conference on Permafrost.

Table C1. Participants from the People's Republic of China at the Fourth International Conference on Permafrost

\*Li Yusheng, vice president, Academy of Railway Sciences, Ministry of Railways, Beijing

Shi Yafeng, professor, director, Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica, and deputy chief, Earth Sciences, Academia Sinica

Cheng Guodong, assistant professor, Director of Forecast and Permafrost Environmental Protection Division, Institute of Glaciology and Cryopedology, Academia Sinica, Lanzhou

\*Chen Guojing, engineer, Road Research Division, Ministry of Communications, Beijing

\*Chen Xiaobai, associate professor, Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica

\* Members, Chinese Railway Delegation.

Table C1 (cont'd). Participants from the People's Republic of China at the Fourth International Conference on Permafrost.

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\*Cui Chenghan, engineer, Research Division, The Third Survey and Design Institute, Ministry of Railways, Tien Jing

Cui Zhijiu, associate professor, Department of Geography, Peking University, Beijing

\*Ding Jingkan, vice chief, Permafrost Division, Northwest Institute, Ministry of Railways, Lanzhou

Liu Hongxu, civil engineer, Heilongjiang Low-Temperature Construction Science Research Institute, Nangang, Harbin

\*Lu Guowei, engineer, Yakeshi Institute of Forest Survey and Design, Inner Mongolia

Qiu Guoqing, assistant professor, Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica, Lanzhou (during 1982-1983, Arizona State University, also University of Alaska, Ohio State University, and CRREL)

\*Wang Hong, deputy director, engineer, Research Division, First Survey and Design Institute, Ministry of Railways, Lanzhou

\*\*Wang Liang, engineer, Water Power Research Institute, Northeast Design Institute, Ministry of Water Resources and Electric Power, Changchun, Jilin

\*\*Xu Bomeng, engineer, Water Power Research Institute, Northeast Design Institute, Ministry of Water Resources and Electric Power, Changchun, Jilin.

Xu Xiaozu, assistant professor, Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica, Lanzhou (presently at CRREL)

\*Zhao Yuehai, interpreter, Foreign Affairs Bureau, Ministry of Railways

\*Zhao Yunlong, engineer, Research Division, Qiqihar Railway Administrative Bureau, Qiqihar

\*Zhou Youwu, associate professor, Vice Director, Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica, Lanzhou

\*\*Zhu Qiang, engineer, Water Resources Dept. of Gansu Province, Water Power Research Institute, Ministry of Water Resources and Electric Power, Qilihe, Lanzhou

Zhu Yuanlin, assistant professor, Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica, Lanzhou.

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\*Members, Chinese Railway Delegation

\*\*Water Resource Group

Table C2. Chinese Railway Delegation Schedule and Participants.

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|            |  |
|------------|--|
| 12 July    | Arrive Anchorage.  |
| 13 July    | Hirail on Alaska Railroad to Whittier and Seward and return.<br>Reception - Alaska World Affairs Council |
| 14-16 July | Alaska Railroad Trip A-1, Anchorage - Fairbanks  |
| 17-22 July | Fourth International Conference on Permafrost - Fairbanks  |
| 23-24 July | Fairbanks - Prudhoe Bay by road  |
| 25 July    | Prudhoe Bay - SOHIO and ARCO facilities  |
| 26-27 July | Barrow - North Slope Borough and NARL  |
| 27 July    | Anchorage - ARCO visit   |
| 28 July    | Anchorage-Arctic Foundations visit and enroute to Seattle  |
| 29 July    | Seattle - Burlington Northern Railroad - Hirail to Everett<br>and through Cascade Tunnel                 |
| 30 July    | University of Washington and Mount St. Helens area   |
| 31 July    | Oregon State University, Department of Civil Engineering   |
| 1 August   | University of California, Berkeley, Department of Civil<br>Engineering and Earthquake Research Center    |
| 2 August   | U.S. Geological Survey, Menlo Park   |
| 3 August   | Bechtel, BART Control Center, and Golden Gate Bridge   |
| 4 August   | Depart for Beijing.  |

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**Table C3. P.R.C. Water Resources Group Post-Conference  
Schedule and Participants**

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23 July - En route, Anchorage to Seattle  
 24 July - Visit Lake Washington locks and drive to Portland  
 25-26 July - Visit North Pacific Division, Corps of Engineers, and  
                   Bonneville Power Administration and Columbia River  
 27 July - Department of Civil Engineering, Oregon State University  
 28 July - San Francisco: Department of Civil Engineering, University of  
                   California, Berkeley  
 29 July - Sacramento: California Department of Water Resources  
 30-31 July - Free time  
 1 August - Depart for P.R.C.

Zhu Qiang, Engineer, Water Resources Department of Gansu Province, Lanzhou  
 Xu Bomeng, Engineer, Water Power Research Institute, Ministry of Water  
                   Resources and Electric Power, Changchun, Jilin  
 Wang Liang, Engineer, Water Power Research Institute, Ministry of Water  
                   Resources and Electric Power, Changchun, Jilin  
 Don Bosco, Corps of Engineers, Washington, DC  
 Len Gaydos, U.S Geological Survey, Ames, CA

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**Table C4. Professor Shi Yafeng's Post-Conference Schedule.**

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28 July - 5 August - U.S. Geological Survey, Tacoma, WA  
 5-8 August - University of Colorado, Boulder, CO  
 8-11 August - CRREL and Dartmouth College, Hanover, NH  
 11-15 August - Mt. Washington, NH, and Boston Museum of Science, MA  
 15-17 August - Washington, DC  
 17-21 August - Ohio State University  
 21-25 August - Arizona State University  
 26-27 August - San Francisco; depart for P.R.C.

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Table C5. Chinese papers published in Proceedings: Fourth International Conference on Permafrost, National Academy Press, Washington, D.C. (1983).

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Chen Xiaobai, Wang Yaqing, and Jiang Ping. Influence of penetration rate, surcharge stress, and groundwater table on frost heave.

Cheng Guodong. Vertical and horizontal zonation of high-altitude permafrost.

Cheng Guodong and Wang Shaoling. Distributive regularities of high ice-content permafrost along Qinghai-Xizang Highway.

Cui Chenghan and Zhou Kaijiong. An experimental study of the frost-heave reaction.

Cui Zhijiu. An investigation of rock glaciers in the Kunlun Shan, China.

Dai Jingbo. Variation regularity of permafrost table beneath embankments in northeast China.

Ding Dwen. Physical nature of frost processes and a research method.

Ding Jingkang. A study of horizontal frost-heaving forces.

Fu Liandi, Ding Dwen, and Guo Dongxin. A study of the evolutionary history of permafrost in northeast China by a numerical method.

Fu Rong, Zhang Jinsheng, and Hou Zhongjie. Ultrasonic velocity in frozen soil.

Guo Pengfei and Cheng Guodong. Zonation and formation history of permafrost in Qilian Mountains of China.

He Changgeng. Building foundations on permafrost.

Huang Xiaoming. Determination of critical height of railroad embankments in the permafrost regions of the Qinghai-Xizang plateau.

Huang Yizhi, Gu Zhongwei, Zeng Zhonggong, He Yixian, and Liu Jinren. A geophysical method for permafrost survey in China.

Li Yusheng, Wang Zhugui, Dai Jingbo, Cui Chenghan, He Changgen, and Zhao Yunlong. Permafrost study and railroad construction in permafrost areas of China.

Liu Hongxu. Calculation of frost-heaving forces in seasonally frozen subsoils.

Lu Guowei, Guo Dongxin, and Dai Jingbo. Basic characteristics of permafrost in northeast China.

Nei Fengming. Preventing frost damage to railway tunnel drainage ditches in cold regions.

Qiu Guoqing, Huang Yizhi, and Li Zuofu. Alpine permafrost in Tian Shan, China.

Shi Yafeng and Cheng Guodong. A brief introduction to permafrost research in China.

Shi Yafeng and Mi Desheng. A comprehensive map of snow, ice, and frozen ground in China (1:4,000,000).

Shu Daode and Huang Xiaoming. Design and construction of cutting at sections of thick-layer ground ice.

Sun Yuliang. Deformability of canals due to freezing and thawing.

Tong Boliang, Li Shude, Zhang Tingjun, and He Yixian. Frozen ground in the Altai Mountains of China.

Tong Changjiang and Yu Chongyun. Research on the frost-heaving force of soils.

Tong Zhiquan. In-situ direct shear tests at the freeze/thaw interface and in thawed soils.

Wang Chunhe. Impact of freeze-thaw of swamp on agricultural production in the Sanjiang Plain of China.

Wang Liang, Xu Bomeng, and Wu Zhijin. Properties of frozen and thawed soil and earth dam construction in winter.

Xia Zhaojun. A study of thermal cracks in frozen ground.

Xu Shuying, Zhang Weixin, Xu Defei, Xu Qizhi, and Shi Shengren. Development of periglacial landforms in the northern marginal region of the Qinghai-Xizang Plateau since the late Pleistocene.

Xu Xiaozu and Wang Jiacheng. A preliminary study of the distribution of frozen ground in China.

Ye Bayou and Yang Hairong. Determination of artificial upper limit of culvert foundation in permafrost areas of the Qinghai-Xizang Plateau.

Zhang Jinsheng and Fu Rong. Preliminary experimental study of water migration at the ice/soil interface.

Zhang Luxing and Ding Jingkang. Long-term resistance of anchors in permafrost.

Zhang Shixiang and Zhu Qiang. A study of the calculation of frost heaving.

Zhang Weixin, Xu Shuying, Xu Qizhi, and Shi Shengren. The periglacial environment of the late Pleistocene along the Qinghai-Xizang Highway.



APPENDIX D: PERMAFROST AND BRIDGE AND CULVERT CONSTRUCTION  
IN THE DA HINGGAN LING, NORTHEAST CHINA

Teng Jiajun  
Yakeshi Institute of Forest Surveys and Designs  
Inner Mongolia, P.R.C.

INTRODUCTION

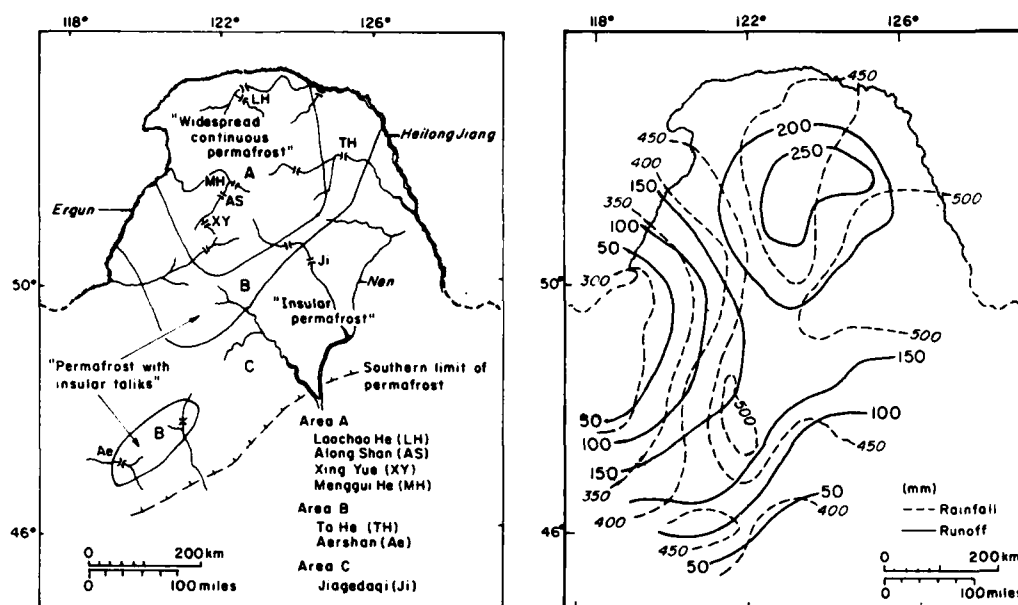
Permafrost exists in the People's Republic of China in the vast area of land from 47° to 53°N and from 119° to 125°E, where the climate is very cold and widespread forest covers the land. At present, human activities are becoming more frequent in this area and all types of construction in forest areas are steadily increasing. Bridge and culvert construction are an important part of the engineering. Most of the bridges are constructed to cross rivers. Therefore, there is a very close relationship between bridge-culvert design and construction and the permafrost in the region.

Construction on permafrost must affect the conditions that maintained the original equilibrium of the natural environment. The problem of preventing and repairing frost damage receives much attention, but we should not neglect to utilize permafrost characteristics effectively in bridge and culvert construction. Research into all of these aspects is very limited. The author will briefly introduce only a few related problems.

PERMAFROST CHARACTERISTICS IN THE BRIDGE-CROSSING REGIONS ALONG RIVERS

Most of the main tributaries of the Ergun and Heilongjiang drainages are located in the "widespread continuous permafrost" zone (A) and "permafrost with insular taliks" zone (B), and most of the main tributaries of the Nenjiang drainage are located in the "insular permafrost" zone (C) (Table D1, Fig. D1a).

The annual average precipitation is 350-450 mm in most parts of zones A and B, and 350-500 mm in most parts of zone C. This is nearly the same as the annual average precipitation of the area to the south of the southern permafrost boundary. However, the annual average runoff in zone A is greater than that in zone B; that in zone B is greater than in zone C, and in zone C is noticeably much greater than in the area to the south of the southern permafrost boundary (Fig. D1b).



a. Permanent bridge sites in permafrost zones.

b. Average annual precipitation and runoff (mm) in northeast China.

Figure D1. Location map of northeast China.

It is very obvious that supra-permafrost water is present above permafrost because the permafrost acts as an impermeable barrier. The ground often has a higher water content during the early summer. Permafrost influences the permeability of the soil, creating the specific runoff conditions in permafrost areas.

According to the records of hydrological stations, most riverflood peaks are formed by runoff from torrential rainfalls, except for a few rivers in the westernmost part of the region. The specific characteristics of runoff conditions in permafrost areas are therefore one of the important factors that must be considered in the calculation of discharge for bridge design.

Table D1. Features of three large river systems.

| River system name | Main tributaries                | Direction of main tributaries |
|-------------------|---------------------------------|-------------------------------|
| Ergun             | Hailar, Beierci, Gen Rivers     | from E to W                   |
| Nen Jiang         | Gan, Nuomin, Yalu, Chaor Rivers | from NW to SE                 |
| Heilong Jiang     | Huma, Emur, Pangu Rivers        | from SW to NE                 |

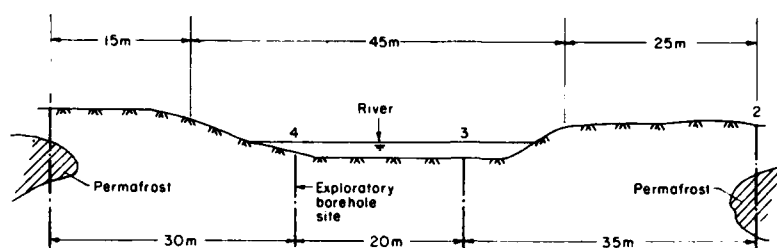


Figure D2. Profile of the Xing Yue bridge site.

In the above-mentioned region, main channels of rivers are shallow and narrow, river floodplains are wide, and there are many paleo-riverbeds. Soil materials are coarse in riverbeds and on river floodland; permeability is very great.

There are no obvious channels in some streams. Water flows slowly along gentle slopes at the mouths of valleys.

Investigation has shown (Table D2 and Fig. D2 and D3a) that, due to the influence of vegetation and landscape features, especially the

Table D2.

| Permafrost zone | River system  | River    | Main channel width (m) | Exploration location                       | Talik width                                   |
|-----------------|---------------|----------|------------------------|--|---|
| A               | Heilong Jiang | Emur     | 100                    | At the site of Laochao He bridge           | 200 m on left bank; permafrost on right bank. |
| A               | Ergun         | Menggui  | about 20               | At the site of Menggui He bridge in Mangui | Beneath the riverbed                          |
| A               | Ergun         | Galayo   | 5-6                    | At the site of Xing Yue bridge in Jinhe    | 10m on the left bank; 20m on the right bank   |
| B               | Heilong Jiang | Huma     | 70-80                  | At Shiba Zhan                              | 1-2 km on both banks                          |
| B               | Heilong Jiang | Walagan  | about 20               | At Walagan                                 | 300-400 m on both banks                       |
| B               | Nen Jiang     | Jiligulu | about 6                | At Kydouer                                 | About 100 m on both banks                     |

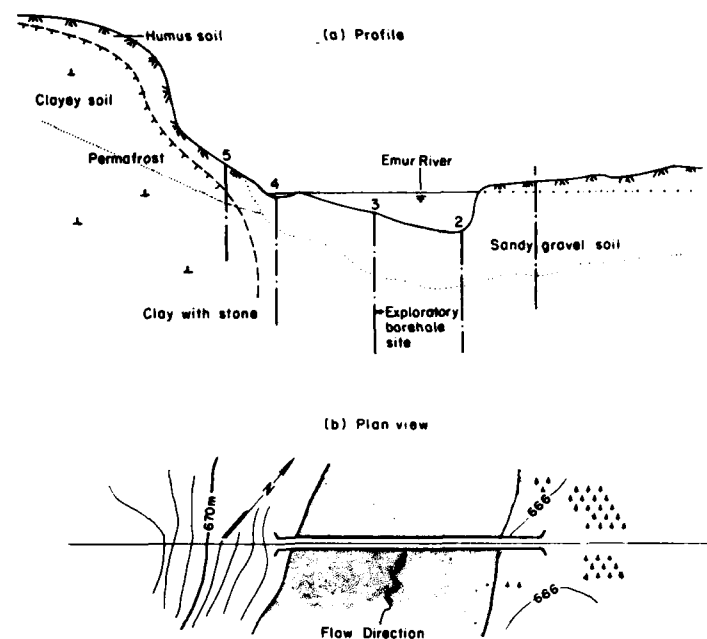


Figure D3. Profile and plan views of Laochao He bridge site.

existence of waterflow, there are obvious differences in the distribution of permafrost between the bridge-crossing regions along rivers and other geomorphological units.

Widespread talik exists in the bridge-crossing regions along large and medium rivers in permafrost zones A and B and also occurs noticeably along some small rivers in zone B. The talik expands gradually from north to south, while permafrost along the rivers exists only as sporadic islands in zone C.

Open or closed taliks also exist beneath the beds of other rivers, such as the Emur, Beierci, Laochao, and Dalin Rivers, which are tributaries of the Beierci, Gen, Deierbuer, and Duobukuer Rivers. The wider and deeper the water surface of a river is, the more heat the soil layer absorbs and the greater the permafrost degradation; thus, the wider the talik.

The left bank of the Laochao River faces to the northeast (Fig. D3b). The 20-m high left bank is sheltered from the sun. There is a silty clay in the upper layer of the ground and the vegetation on the left bank is more dense than on the right. Talik exists on the right bank while permafrost is found on the left bank. It is obvious that the south-facing bank absorbs greater heat than the north-facing bank. The heat capacity of clayey soil is greater than that of sandy soil, but its permeability is

less. Dense vegetation is more favourable in preserving the heat of permafrost than is sparse vegetation and at the same time it decreases the soil's absorption of solar energy. The total influence of these factors has caused permafrost to be preserved on the left bank of the river (Fig. D3a).

In overflow rivulets without defined channels, permafrost distribution is generally continuous in the bridge-crossing region except for taliks and the fringe areas of permafrost. The vegetation is thick bryophyte or else the upper layer of ground is peat. Because of the heat-preserving influence of the vegetation and the low heat conductivity of peat (0.34 cal/m hr°C), the ice content of the permafrost is high and it often exhibits ice layers of different thicknesses. The upper table of permafrost is shallow, about 0.5 to 1.0 m.

River water thermal action terrain features, properties of the upper

Table D3. Factors influencing bridge-crossing regions along rivers.

| <u>Name of phenomenon</u> | <u>Distribution</u>  | <u>Influence on bridge and culvert engineering</u>  |
|---------------------------|--|---|
| Thick ground ice          | Often found beneath overflow rivulets without beds and rivulet beds  | Large and medium bridges do not meet thick ground ice. When choosing the site of small bridges, one must pay great attention to whether thick ground ice exists. Serious damage to bridge and culvert structures can be caused by the instability of ground ice and its disappearance when thermally disturbed. |
| Icing, "pingo"            | River floodlands, rivulet riverbeds, and fringe areas of alluvial fans in the front range can develop icing and "pingos"   | When plugging culverts and bridge openings, it can crack structures as it expands or by pushing bridge piers, causing them to lean. Bridges and culverts should avoid icing and "pingo" and avert the formation of near icing and "pingo."  |
| Solifluction (landslide)  | On steep slopes, soil thawing in spring and water penetrating into the freeze/thaw face cause soil bodies to slip along the face.  | Generally speaking, this has little influence on bridge and culvert engineering but one must pay attention to the possibility of slides, which may plug bridge openings and riverbeds.  |
| Thermo-settlement         | Due to the influence of natural or artificial factors; the thermo-balance condition of permafrost is destroyed, resulting in permafrost thaw. Lowering of the permafrost table and foundation settlement mostly appear in unstable permafrost regions. | If we avoid thick ground ice, dig foundations in summer, and avoid prolonged exposure to sunlight, at the same time following the principles of design for thawed regions, then generally speaking very few bridge and culvert structures will be destroyed by thaw settlement of permafrost.                   |
| Ice plugging              | Some groundwater flows out of the ground surface through culverts or bridge openings and freezes, gradually stopping up the culverts and bridge openings.  | Frost cracks form easily. The bridge openings or culverts should be enlarged appropriately, and drainage ditches should be dredged.   |

layer of the ground, and type of vegetation are the main factors that affect the characteristics of permafrost distribution in the bridge-crossing region along rivers. There are also many kinds of harmful geological phenomena in the bridge-crossing regions along rivers (Table D3).

In summary, many factors influence permafrost characteristics in the bridge-crossing regions along rivers, and the influence of these factors on bridge and culvert engineering is very complicated. Much work needs to be done to provide a reliable basis for the comparison of bridge-culvert plans, the choosing of bridge sites, and bridge-culvert structural design.

#### FROST DAMAGE CONDITIONS OF BRIDGE AND CULVERT CONSTRUCTION AND PREVENTIVE AND MAINTENANCE MEASURES

##### Permanent Large and Medium Bridges

##### Structural Characteristics

The types of structures and foundations are classified in Table D4. Some superstructures are static, others are superstatic (see Figure D4 for details of the types of substructures most in use).

Table D4. Types of bridges and foundations.

| Name of bridge | Type of superstructure                                      | Type of substructure           | Base embedded depth (m) | Permafrost zone |
|----------------|---|--------------------------------|-------------------------|-----------------|
| Laochao        | Double-vaulted arch (4 x 30 m)                              | Borehole pouring piles         | 9                       | A               |
| Ta He          | Double-vaulted arch (9 x 28 m)                              | Open digging and enlarged base | 4-5                     | B               |
| Along Shan     | Reinforced concrete double cantilever (5 x 25 and 2 x 10 m) | Borehole pouring piles         | 8                       | C               |
| Jiagedaqi      | Reinforced concrete simple-supported beam (6 x 20 m)        | Sunken shaft foundation        | 6                       | D               |
| Aershan        | Reinforced concrete simple-supported beam (1x27 m)          | Open digging and enlarged base | 4-5                     | E               |

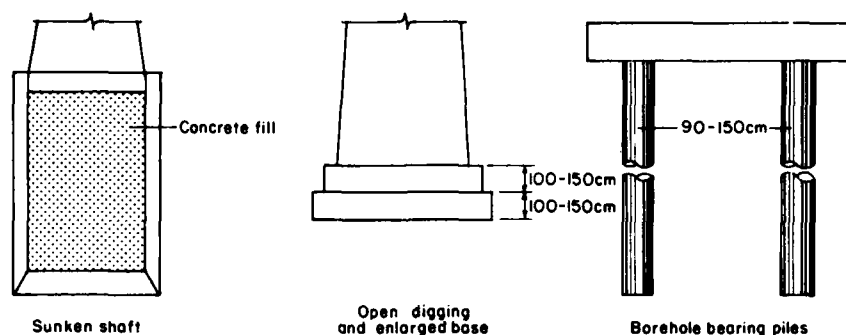


Figure D4. Most commonly used substructure.

### Frost Damage Conditions

Because of deeply embedded bases, good soil materials, and location in the taliks of the bridge-crossing regions, large bridges have not encountered noticeable frost-damage phenomena, and very little has been observed on medium bridges. However, considerable attention should be paid to the following conditions:

(i) After the Nenlin Railway was opened to traffic, it was reported that two medium bridges suffered frost damage that affected the safety of trains. The bridge-building activity had changed groundwater conditions, causing icing to form in the upper reaches of the bridge pier, resulting in heaving and inclination. The center line of the Yindaluchi River bridge inclined upstream as much as 6 cm (Fig. D5).

(ii) The pier of a medium bridge (2-15 m) on the Amur River was constructed with bored piles (pile diameter 1.0 m). The deck above the pier was noticeably raised 3 to 5 cm. Preliminary analysis has shown a relation to frost heave.

(iii) Some bridges have used prefabricated hollow reinforced tube piles, with water and concrete poured into the hollow tubes. Because of frost heave of the mud in the tube, the pile walls suffered many vertical cracks (Fig. D6).

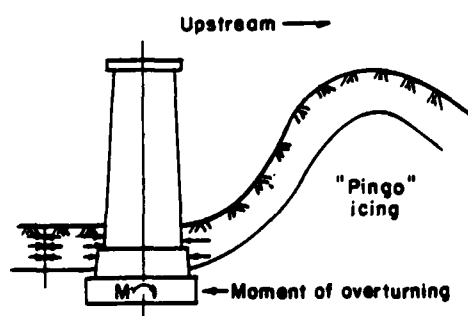


Figure D5. Interaction between bridge pier and "pingo" (icing) at the Yindaluchi River crossing.

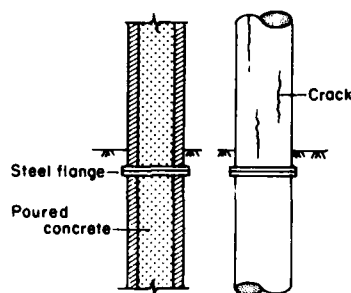


Figure D6. Vertical cracks in prefabricated tube piles.

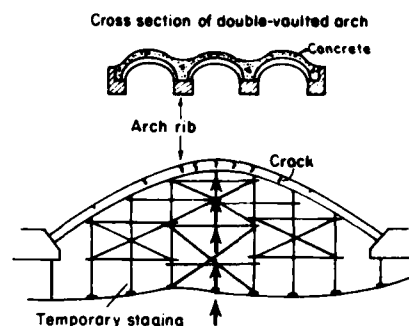


Figure D7. Arch rib cracked by upward thrust of arch center.

(iv) Because the arch centers of two double-vaulted arch bridges were not dismantled during winter construction and the space between the arch center and arch rib was too small, the arch centers were lifted by frost heave and the arch ribs were pushed up and cracked in many places. (Fig. D7).

Although frost damage of large and medium bridges is very infrequent, we must not ignore the problem. Not only should harmful permafrost geological phenomena, such as icing and "pingos," be avoided under natural conditions, but bridges must also be designed and built well to take into account the new circumstances created by artificial activities and to avoid new icing, "pingos," etc. Frost damage should be considered in the course of construction and its occurrence prevented.

#### Permanent Small Bridges and Culverts

##### Structural Characteristics

**Small bridges:** Most of the superstructures are simple-supported beams made of reinforced concrete; a few use the double-vaulted arch. Most of the substructures are gravity piers and abutments of concrete with enlarged bases in open dug pits. The embedded depth of the base is usually 3 m or more.

**Culverts:** Most of the culverts are reinforced concrete tube culverts or plate-covered culverts with separating section bases that were built by laying piece stone, stone blocks, concrete, or reinforced concrete. The base ends are about 2 to 3 m below ground, and the base center is about 1 to 1.5 m. Permanent culverts are rare in the roads of forest regions. Many more culverts are used for the railways.



Table D5. Comparison of influence of seasonally frozen and thawed ground.

| Features                | Seasonally active layer   |  | Influence on bridge and culvert structures   |
|-------------------------|---|--|--|
|                         | Seasonally frozen ground  | Seasonally thawed ground   |  |
| (1)<br>Definition       | Seasonally frozen layer in every type of talik.   | Seasonally thawed layer above permafrost table   | Frost damage of bridge-culvert structure is produced by frost-thaw replacements  |
| (2)<br>Thickness        | Thickness increases from south to north. In the same region thickness of seasonally frozen ground is greater than that of seasonally thawed ground (Table 6). | Thickness decreases from south to north, but it changes with different terrain vegetation and soil materials (Table D7).                                   | In seasonally frozen ground, the embedded depth of the foundation is more stable. In seasonally thawed ground, even in the same region, the embedded depth of foundation may be different. |
| (3)<br>Temperature      | Mean annual ground temperature is higher than 0°C.  | Mean annual ground temperature equal or lower than 0°C.  | Near bridge and culvert foundation, the mean annual ground temperature may change.   |
| (4)<br>Active direction | Freezing from one direction. Thawing from two directions. The thawing from upper layer is faster than that from lower to upper.                               | Thawing from one direction, freezing from two directions. The freezing rate from upper layer to lower layer is greater than that from lower to upper layer | The foundation suffers large early frost heave force in seasonally frozen ground   |
| (5)<br>Active time      | Long frozen period (at Yakeshi 170 days)<br><br>Short thaw period (at Yakeshi 90 days)  | Long thaw period (at Yakeshi 200 days)<br><br>Short frozen period (at Yakeshi 60 days)   | Under the same conditions short frozen period. High ratio of penetration maybe frost heave force great.  |

#### Frost Damage Conditions

(1) Seasonally frozen and thawed ground: Small bridge and culvert bases are shallow; therefore, they have a very close relation with the seasonally frozen layer in talik areas and the seasonally thawed layer in permafrost areas. Table D5 shows the comparisons between the main characteristics of these two.

Table D6.

| Place name | Latitude (N) | Depth of seasonally frozen ground | Period of record           | Permafrost zone |
|------------|--------------|-----------------------------------|----------------------------|-----------------|
| Yakeshi    | 49°16'       | 3.00 m                            | 1961-1970                  | C               |
| Genhao     | 50°41'       | 2.95 m                            | 1961-1970                  | B               |
| Mohao      | 53°29'       | 3.00 m                            | Based on investigated data | A               |

Table D7.

| Vegetation types                     | Peat          | Bryophyte          | Betula fruticosa<br>Vaccinium uliginosum, etc. | Forest and grass               |     |
|--------------------------------------|---------------|--------------------|--|--------------------------------|-----|
| Soil condition                       | Ice-rich peat | Silt clay with ice | Silt clay with stone                           | Silt clay with sand and gravel |     |
| Depth of seasonally thawed layer (m) | 0.5-1.0       | 1.0-1.5            | 1.5-2.0  | 2.0                            | 2.5 |

(ii) Frost damage conditions of small bridges and culverts are given in Table D8.

#### Prevention and Repair Measures

Based on the reported data and our own experience, we consider the following main points should be given great attention.

##### Small bridges:

(i) Harmful permafrost geological areas should be avoided in selecting sites.

(ii) In appropriate places on the upper reaches of riverlets where icing and "pingos" may be produced by the influence of artificial activities, frost ditches should be dug to lower groundwater levels and to keep icing and "pingos" far from bridge sites.

(iii) Frost-heave-susceptible soil should be exchanged for soil that is not susceptible to frost heave. Pier bodies or foundations under the ground surface should be tapered to decrease tangential frost-heave force (Fig. D8).

Table D8. Frost damage to small bridges and culverts.

| Name of structure                                   | Frost damage conditions  | Cause   |
|---|--|---|
| Small bridges<br>(suffering very few frost damages) | Due to the great strength of abutment resistance to icing, pingo, and frost heave, frost damage usually occurs from pushing up or inclination of pier body, which may return to its original position after thawing.   | If clayey soil layer thick in foundation, active condition of water under pressure is changed by artificial activities and icing and pingo form easily. In addition to the great tangential frost heave force, the piers push up or incline.  |
| Culverts<br>(frost damages up to 50% or more)       | <ol style="list-style-type: none"> <li>1. Wing wall cracks, leans outward</li> <li>2. Culvert waist falls, ends high and middle low</li> <li>3. Foundation staggering</li> <li>4. Higher end tube section was pushed out</li> <li>5. Tube section jointings crack</li> </ol> | <ol style="list-style-type: none"> <li>1. Frost heave in the sides of roadbed or vertical frost heave at the tube ends.</li> <li>2. Force of roadbed pressure at middle is greater than that at ends. Vertical frost heave at middle part is smaller than that at the ends, if thaw settlement at middle part is greater than that at the ends.</li> <li>3. Undisturbed frost heave or thawing settlement</li> <li>4. Produced by pushing up of side frost heave of roadbed soil.</li> <li>5. Lateral frost heave force of roadbed soil.</li> </ol> |

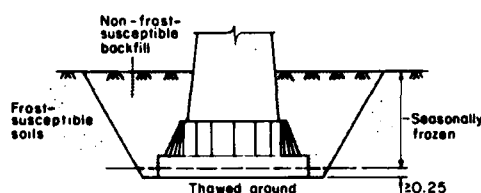


Figure D8. Measures taken for prevention and repair of frost damage to small bridge piers.

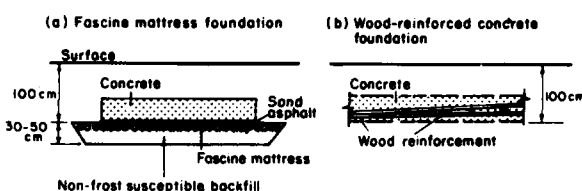


Figure D9. Foundation shape of a frost-heave-proofed culvert.

(iv) The depth of foundations is to be embedded in permafrost. Generally speaking, we should treat it the same as one that is built on thawed ground.

#### Culverts:

(i) Harmful permafrost geological areas should be avoided in selecting sites.

(ii) The hole diameter of the culvert should not be too small. Under common conditions, culvert diameter is 1.0 m. If icing and pingo exist upstream, the culvert diameter should be 2.0 m.

(iii) Pressured culverts of end tube section lift up should not be used, but the hole diameter should be enlarged.

(iv) The culvert body should be designed with a certain arching factor.

(v) When designing bridges in stable permafrost areas, such as north-facing slopes, thick peat layers, and areas far from river taliks and frequent human activity, we can consider that the ground will remain in a frozen condition.

(vi) If the design principles allow for thawing of the foundation soil, a good effect will be obtained by using wood-reinforced concrete foundations (see Fig. D9 for detail).

(vii) If the foundation is embedded in the seasonally frozen layer, the embedded depth of the foundation near the mouth of a culvert should be decided by the frost-heave susceptibility of the foundation soil. At the same time consideration should be given to whether frost-heave-susceptible soil might be exchanged for soil that is not susceptible to frost-heave.

#### Wooden Bridges and Culverts

Wooden bridges and wooden culverts are mainly used for roads in forest areas.

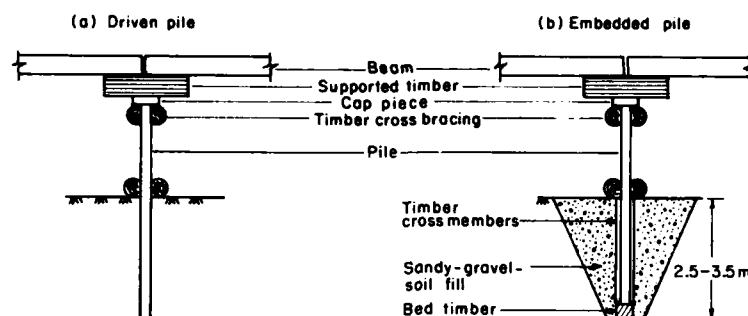


Figure D10. Substructure of wooden bridges.

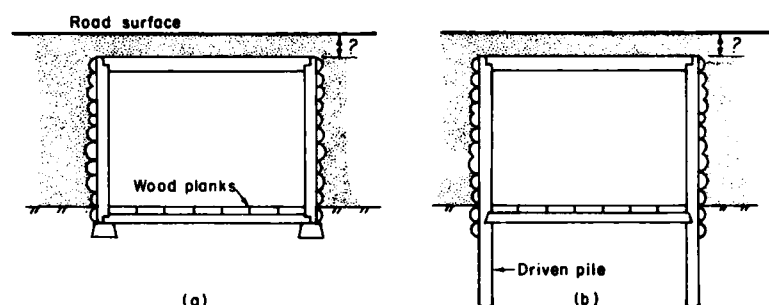


Figure D11. Wooden culvert structures.

### Structural Characteristics

**Wooden bridges:** Most of the superstructures are simple-supported beam and framed beam; the substructures are driven pile or embedded pile raft-frame (see Fig. D10).

**Wooden culverts:** The structural type shown in Figure D11 is generally used.

### Frost Damage Conditions

The foundations of wooden bridges and culverts are usually embedded in the seasonally frozen or seasonally thawed ground layer. Most wooden bridges are affected by frost damage. Investigation has indicated that the type shown in Figure D10b is better than that shown in Figure D10a. Frost heave makes wooden piles lift up, but they cannot return to their original position in summer. As a result, the bridge surface rises, and the deck becomes convex. In serious cases, in order to flatten the deck, the part of the pile top lifted up has to be cut every year. After years the wooden piles are pulled out of the ground. If icings occur, the conditions are even more serious. For example, the pier of a wooden bridge that was built in icing in Wurqihan was raised 50 cm every year by frost heave.

Frost damage of wooden culverts is even more widespread. The upper surface of almost all culverts is higher than the road surface. As a result, hunchback phenomena appear on the road surface, making it very unstable for driving.

#### Prevention and Repair Measures

Wooden bridges and culverts are usually used in temporary road engineering, but in main and main feeder highway construction, wooden bridges and culverts are used as little as possible.

It would be best to use the type shown in Figure D10b for wooden bridge foundations, and it would be better to use the type that is similar to that shown in Figure D11b for wooden culverts with retaining piles. If necessary, the original soil should be replaced with soil that is not susceptible to frost heave and the bottom should be protected with rubble.

#### APPLICATION OF PERMAFROST CHARACTERISTICS IN BRIDGE AND CULVERT CONSTRUCTION

As soil is frozen, porous materials are frozen into the whole body; impermeability, compression strength, and shear strength increase greatly. If these factors can be used in bridge and culvert engineering, both the work of engineering and the cost can be decreased. Up to now very few of them have been used, but let me introduce the following examples.

1. One problem that is frequently encountered within developing northern forest areas is how to preserve the permafrost foundation in a frozen condition in order to solve the low bearing capacity of the foundation. For example, the bearing capacity of thawed silty sand is very low, but after it is frozen with a water content of 20% and a temperature of  $-1.3^{\circ}\text{C}$ , the uniaxial-ultimate compression strength is up to  $105 \text{ kg/cm}^2$ . Although this conclusion is based on experimental data, it may indicate that the strength of frozen soil has great potential in the practice of construction.

2. An experiment was conducted using anchor structures in frozen ground to stabilize anchor piles. In the course of this bored pile experiment, the lift phenomenon of the anchor piles was overcome by using the anchor structures shown in Figure D12. The experiment was conducted in November with the air temperature below  $-20^{\circ}\text{C}$ . The soil around the pile was clayey silt. Table D9 gives some experimental results. It is estimated that the shear stress of silty clay is up to  $0.4 \text{ kg/cm}^2$  at the maximum load. Thus it can be seen that greater potentiality exists.

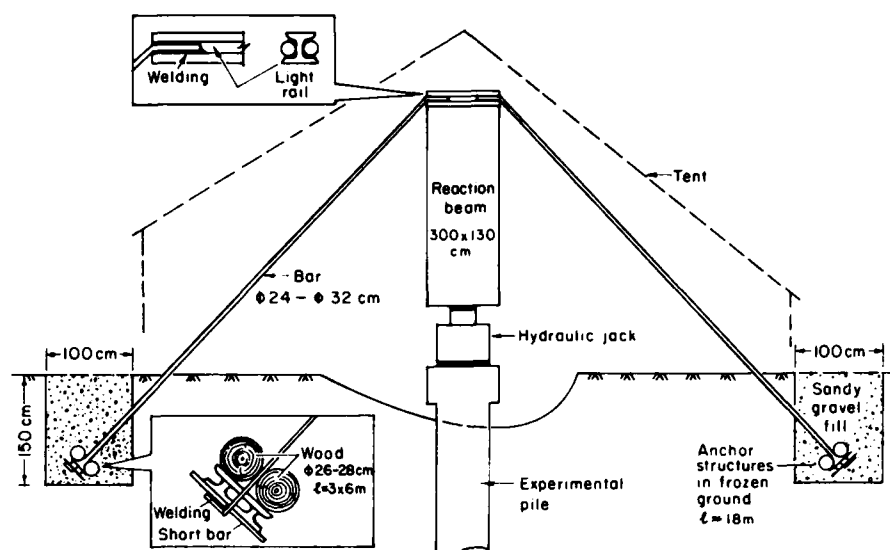


Figure D12. Frozen anchor structure.

Table D9. Results of anchor pile test.

| File number | Load of anchor pile<br>at pushing up | Last load after<br>stabilizing |
|-------------|--------------------------------------|--------------------------------|
| I           | 240 T                                | 440 T                          |
| II          | 440 T                                | 600 T                          |

3. Digging the foundation pit using the freezing method is widely used in bridge and culvert construction for this region. For example, all of the foundation pits of the Ta He bridge were dug using the freezing method. It is more advantageous to dig foundation pits for small bridges and culvert foundations using the freezing method because pumping equipment and other machinery can be saved and the amount of digging to be done is small. In addition, the construction period is as long as 6-7 months.

#### INFLUENCE OF BRIDGE AND CULVERT CONSTRUCTION ON PERMAFROST ENVIRONMENTS

Bridge and culvert structures and their construction processes must influence the permafrost environment. Unfortunately, little attention has been paid to this question and detailed investigation has not been carried out. The following descriptions give only several problems that are often encountered during construction.

Table D10. Thermal conductivity.

| Soil or material name | Thermal conductivity<br>(cal/m hr°C) | Ratio with peat<br>thermal conductivity |
|-----------------------|--------------------------------------|---|
| Peat                  | 0.34                                 | 1                                       |
| Foundation masonry    | 1.1-1.33                             | 3.2-3.9                                 |
| Sandy clay            | 1.43                                 | 4.2                                     |

1. Although bridge and culvert structures are sporadic, isolated, and cool, their thermal conductivity is great (see Table D10 for data). During the construction process, permafrost vegetation is often destroyed, especially forest, which is very hard to replace. Sometimes, in order to increase the bearing capacity of the foundation, the peat layer must be removed. In addition, bridge and culvert structures concentrate water flow, and the heat exchange between water and soil increases. Therefore, the heat balance of permafrost is destroyed, causing the permafrost table to descend. The information we have shows that the influence of bridge and culvert construction on the upper table of permafrost is not great in the region where permafrost is relatively stable. However, where the permafrost is relatively unstable, the changing depth of the upper table of permafrost is considerable, sometimes up to 6 m or more. It is very important for bridge and culvert design to determine reliably the artificial upper permafrost table.

2. Bridge and culvert foundation engineering destroys the natural motion of groundwater. New icing and "pingos" may appear or the original icing or "pingos" may move or disappear.

3. Digging new riverbeds changes the runoff location of the ground surface water, causing the river taliks to change.

When planning and designing bridges and culverts, it is advantageous to consider the influence of bridge and culvert construction on the equilibrium conditions of the original natural environment, not only for the stability and safety of the bridge and culvert structure, but for the protection of the natural environment as well.

#### CONCLUSION

To sum up, bridge and culvert construction in the permafrost region of the Da Hinggan Ling has its special characteristics. A great deal of work



has been done, especially by the railway system, which has accumulated some experience and data. But the problems of the micro-regional characteristics of permafrost in the bridge-crossing region along rivers, of the methods of calculating bridge and culvert discharge, of the influence of harmful permafrost geological phenomena, of the prevention and repair of frost damage, of how to use permafrost characteristics in bridge and culvert construction, and of the influence of bridge and culvert construction on the original natural environment need to be researched further to serve the development of engineering construction in this region.

## APPENDIX E

### INTRODUCTION TO THE STUDY OF RAILWAY CONSTRUCTION IN THE PERMAFROST REGION OF THE DA HINGGAN LING

QIQIHAR RESEARCH INSTITUTE OF  
SCIENCE AND TECHNOLOGY  
HARBIN RAILWAY ADMINISTRATION

Translation sponsored by

Atlantic Richfield Company  
and  
GeoTec Services Inc.

1984

#### Translation Note

Where uncertainty exists concerning exact translation to English, the literal translation is used. The reader can therefore use his own interpretation as to the true meaning. Queried remarks in parentheses have been provided in some cases by the translator to aid the reader. The translated text was initially edited by Michael Metz.

#### PREFACE

The permafrost region in the Da Hinggan Ling is one of China's main permafrost distributions. Its area is approximately  $38.2 \times 10^4$  km<sup>2</sup>. The geographical position is 115°30' to 130°50'E and 45°10' to 53°20'N. Elevation is from 500 to 1300 m above sea level. Both the Yalin Line and the Nunlin Line railways extend into this main forest region of China's northeast. This permafrost region in the Da Hinggan Mountains is the southernmost part of the Eurasian permafrost region. The distribution patterns of the permafrost region are complicated and show strong seasonal freezing and thawing effects. The fully developed physical and geographical phenomena of the permafrost greatly affect railway construction, transportation, and productivity.

The Qiqihar Railway Research Institute has been studying permafrost railway construction for more than a decade. They have, with the cooperation of other Chinese permafrost research units, studied the following subjects:

1. The distribution of permafrost along the railways in the Da Hinggan Mountains.
2. Regional characteristics of permafrost.
3. Investigation and treatment of icings and icing mounds along the railways.
4. Investigation of frost damage to buildings and thawing patterns of the ground in frost regions.
5. Treatment of railway roadbed settlement.
6. Treatment of bridge foundation settlement.
7. Ventilation and defrosting of tunnels in the cold region.
8. Insulated building foundations.
9. Foundations for elevated buildings.

In recent years, advanced studies in science and technology, theoretical studies on the thaw of permafrost in building soils, the adoption of geotexture in water control construction, the use of the electrical resistivity method in the delineation of groundwater sources in permafrost, and new studies on the temperature of bedrock around tunnels have pushed the theoretical studies of permafrost and the construction in permafrost areas to a new stage.

#### DISTRIBUTION OF PERMAFROST ALONG THE RAILWAY

The trunk lines and spurs of the Yalin and Nunlin railways that service the Da Hinggan Ling area total 1512 km. Of this length, 540 km (or 36%) are on sections of permafrost. The patterns of permafrost in this area include: a continuous permafrost region, a discontinuous permafrost region, and a sporadic permafrost region, as shown in Figure E1.\*

This figure covers the area between 120°45' to 125°15'E longitude and 49°10' to 53°00'N latitude. The west and northwest slopes of the Da Hinggan Mountains (or along the Yalin railway north of Tulihe) belong to the continuous region of permafrost. In this region 76% of the railway is on permafrost. The area north of the line formed by Muyuan Station (on the

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\* Editor's note: See the text of the main report for equivalent Chinese terminology and zonation. No attempt has been made in this translation to standardize usage of permafrost terminology. Regions I, II, and III are approximately equivalent to zones A, B, and C, respectively.

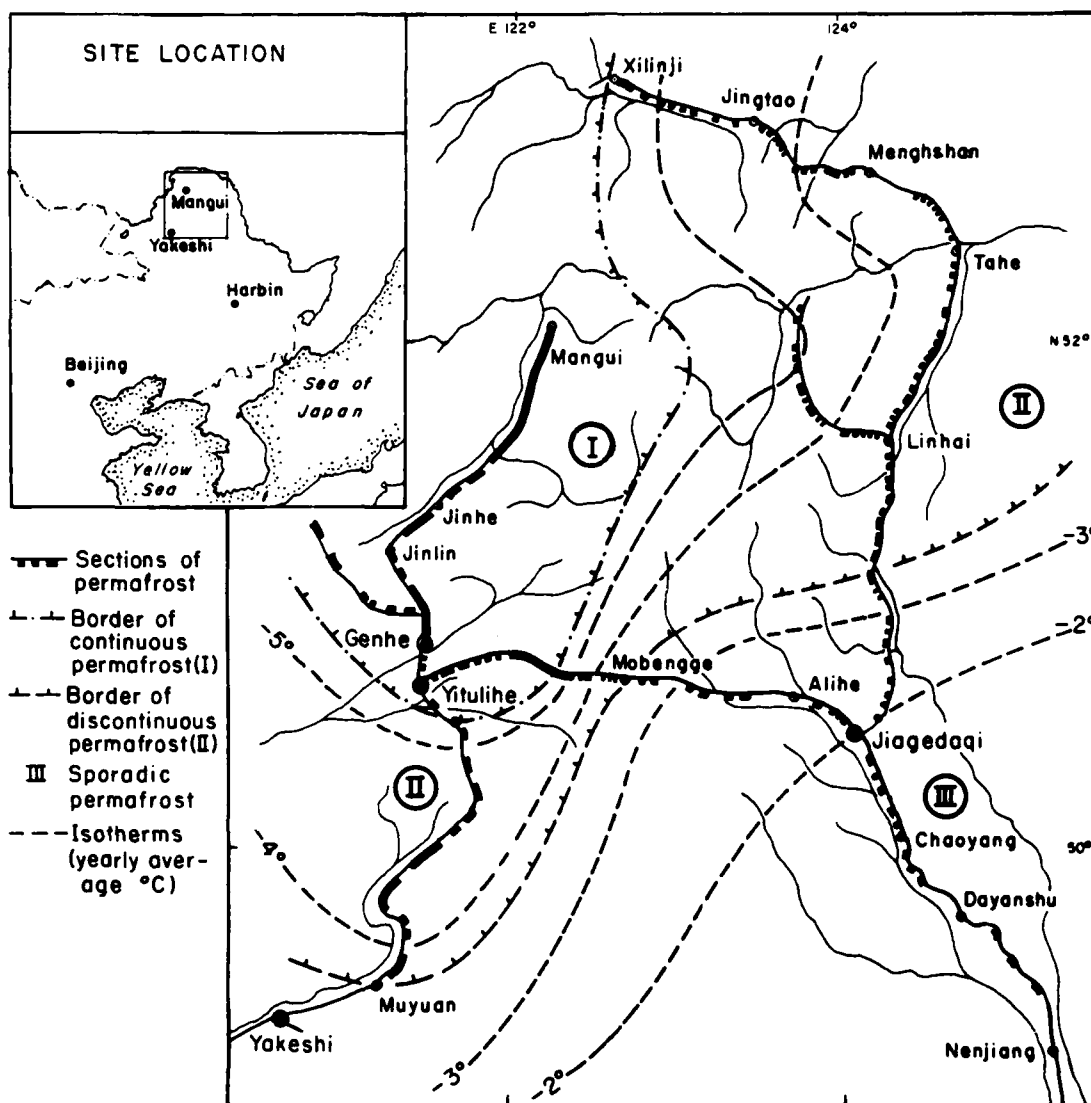


Fig. E1. Map of permafrost distribution along the railways in the Da Hinggan Ling region.

Yalin Line), Molgengge Station (on the I-Jia Railway), and Hailayf Station (on the Nunlin Railway) belongs to the discontinuous permafrost region. Within this region 38% of the railways are on permafrost. South of this line is the sporadic permafrost region. In this area, only about 10% of the 460 km of railway that start from Yakeshi Station and Nengjiang Station are on permafrost.

The southern border of the permafrost region in the Da Hinggan Ling area is on a line formed by Laolai (on the Funan Railway) to Wuchagou (on the Bai-A Railway). (This line has not been included in Figure E1.)

## REGIONAL CHARACTERISTICS OF PERMAFROST ALONG THE RAILWAYS

### Horizontal and Vertical Distribution (Table E1)

#### Characteristics of horizontal distribution :

- a. The region of continuous permafrost distribution (Region I on Figure E1) is mainly on the west and north slopes of the Da Hinggan Mountains, or along the Yalin Railway north of Tulihe and along the extension of the Chao-Wu Railway. This is also the region north of the  $-5^{\circ}\text{C}$  (air?) isotherm.
- b. The region of discontinuous permafrost distribution (Region II on Fig. E1) is located mainly to the south of Region I or approximately north of the  $-3^{\circ}\text{C}$  (air?) isotherm.
- c. The region of sporadic distribution (Region III of Fig. E1) is located mainly to the south of Region II. The southern border coincides approximately with the  $0^{\circ}\text{C}$  (air?) isotherm.

#### Characteristics of vertical distribution:

- a. Connected permafrost region: In the continuous permafrost region, the permafrost areas are connected vertically. The seasonally active layer of this region is shallower, with an average depth of 0.5 to 1.2 m. The permafrost is about 60 to 120 m thick.
- b. Connected and disconnected permafrost regions: These conditions coincide with the horizontally discontinuous permafrost region (Region II of Fig. E1). The connected permafrost has a seasonally active layer up to 2 m thick. The temperature of the permafrost is higher than the temperature of the permafrost in Region I in Figure E1. The disconnected permafrost has a deeper upper limit. The permafrost is between 30 and 60 m thick.
- c. Sporadically distributed permafrost looks like lenses in vertical distribution. They are less than 10 m thick. The seasonally active layer is more than 2.5 m deep. the temperature of the permafrost is  $-0.1^{\circ}\text{C}$  to  $-0.5^{\circ}\text{C}$ . If the ground cover is disturbed or damaged, permafrost cannot exist.

The heat of rivers acts on the permafrost under the riverbed to form thawed or thawing areas. The width of these thaw areas and whether they connect to one another depends on the size of the river and the water temperature. The thaw area of the great riverbeds may extend 10 to 15 m into the riverbank. The tributaries of the great rivers, like the Da Lin,

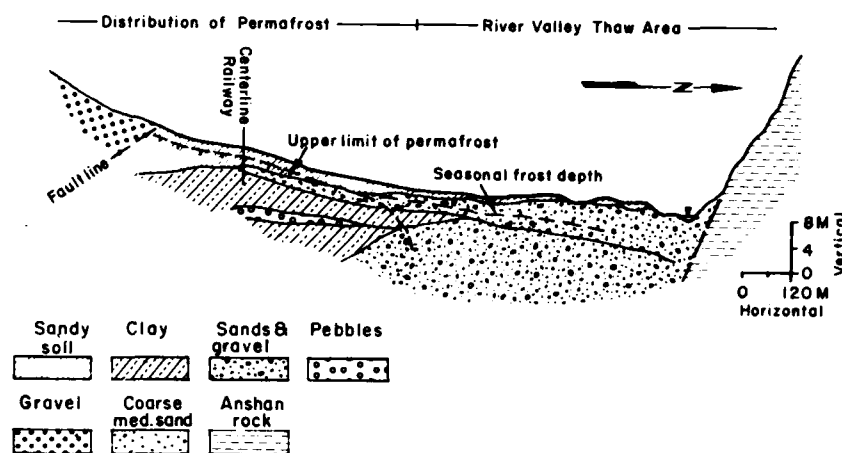


Fig. E2. Geological cross-section of Mangui area river valley construction work.

Beierci, Newer, and Gen Rivers, also have thaw areas, connected or not connected, under their riverbeds (see Fig. E2).

#### Temperature and Thickness of Permafrost

The permafrost region of the Da Hinggan Ling is mainly hilly country. Although the elevation above sea level is not great, it has become one of the coldest areas on earth because of its high latitude and the influence of the Siberian high pressure. The predominant natural conditions and characteristics of permafrost are obviously controlled by the latitude. The average yearly temperature of permafrost increases from the north to the south. Roughly speaking, with the decrease of  $1^\circ$  latitude, the atmospheric temperature rises  $1^\circ\text{C}$  and the average annual temperature rises  $0.5^\circ\text{C}$ . The continuity of the permafrost distribution also varies according to the latitude. The area of permafrost decreases from 70% to 80% in the vast continuous permafrost region to 10% or under 5% in the sporadic permafrost region, and the thickness of the permafrost decreases from 60-120 m

Table E1.

| Region | Average yearly atmospheric temperature ( $^\circ\text{C}$ ) | Average yearly ground temperature ( $^\circ\text{C}$ ) | Continuity of permafrost distribution (%) | Thickness of permafrost (m) | Depth of zero amplitude (m) |
|--------|---|--|---|-----------------------------|-----------------------------|
| I      | $< -5$  | $-3.5 \sim 1.0$  | $70 \sim 80$                              | $60 \sim 120$               | $12 \sim 16$                |
| II     | $-5 \sim -3$  | $-1.5 \sim -0.5$                                       | $50 \sim 60$                              | $30 \sim 60$                |                             |
| III    | $-3 \sim 0$   | $-1.0 \sim 0$  | $10 \sim 30$                              | $5 \sim 20$                 |                             |

Table E2.

| Locality  | Permafrost region | Latitude (N) | Elevation (m) | Average yearly atmospheric temperature (m) | Average yearly ground temperature (°C) | Depth of zero amplitude (m) |
|-----------|-------------------|--------------|---------------|--|--|-----------------------------|
| Mangui    | I                 | 52°02'       | 880           | -5.3                                       | -2.3                                   | 14                          |
| Yitulihe  | I                 | 50°38'       | 990           | -5.2                                       | -0.8                                   | 13                          |
| Yakeshi   | III               | 49°24'       | 667           | -2.9                                       | -0.2                                   |                             |
| Jingtao   | II                | 52°50'       | 747           | -5.4                                       | -1.7                                   |                             |
| Cuiling   | II                | 51°40'       | 1072          | -4.6                                       | -1.3                                   |                             |
| Jiagedaqi | III               | 50°23'       | 382           | -1.4                                       | -0.1                                   |                             |

in the north to 5-20 m in the south. The temperature data of permafrost at points and stations along the railways, as shown in Table E2, indicate that there is a general tendency for the yearly average temperature of the permafrost to follow the latitude change, but in local areas it varies with land and surface features. Figure E3 shows the geothermal distribution along different geographical features within a river valley.

There are four basic patterns of geothermal curves for permafrost areas: positive geothermal gradient curves, negative geothermal gradient curves, zero geothermal gradient curves, and twisted pattern geothermal curves, as shown in Figure E4.

The positive geothermal curve is the typical permafrost temperature curve for the vast, continuous permafrost region and discontinuous permafrost region. The negative geothermal gradient curve is generally the result of the influence of human activities over a long period of time. The

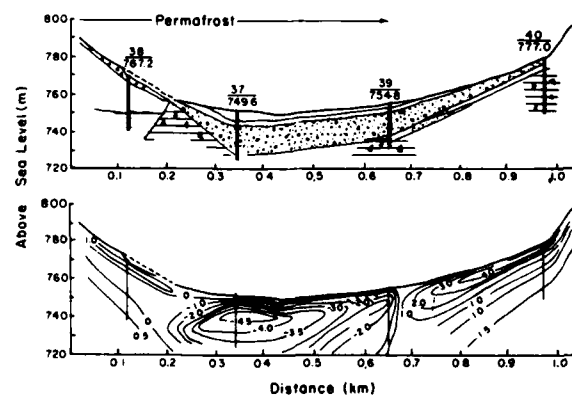


Fig. E3. Geothermal distribution along different geographical features within the river valley.

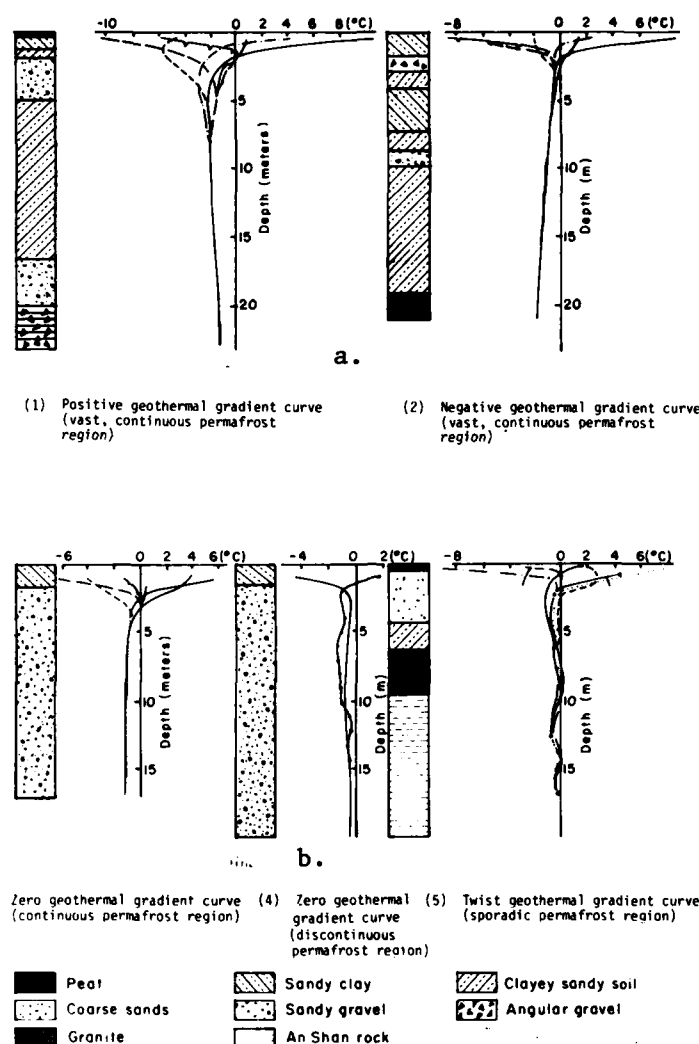


Fig. E4. Geothermal curves. a) Type I. b) Type II.

zero geothermal gradient curve exists mainly in the sporadic permafrost region, or is the transitional pattern between the positive geothermal gradient curve and the negative geothermal gradient curve caused by prolonged human activities in the continuous and the discontinuous permafrost regions.

#### Depth of the Upper Limit of Permafrost

The depth of the upper limit of permafrost in the Da Hinggan Ling area varies according to the soil characteristics and the condition of the vegetative coverage. The representative upper limit of different kinds of soils is shown in Table E3.



Table E3.

| Upper limit (m)<br>heat preservation | Type of soil |      |                        |               |                                  |
|--------------------------------------|--------------|------|------------------------|---------------|----------------------------------|
|                                      | Peat         | Clay | Soil<br>with<br>gravel | Sandy<br>soil | Sands,<br>pebbles,<br>and gravel |
| Poor                                 | 0.85         | 1.9  | 2.6                    | 2.3           | 3.7                              |
| Average                              | 0.65         | 1.5  | 2.1                    | 1.8           | 3.1                              |
| Good                                 | 0.45         | 1.1  | 1.6                    | 1.3           | 2.5                              |



Fig. E5. Features of the field with ground ice.

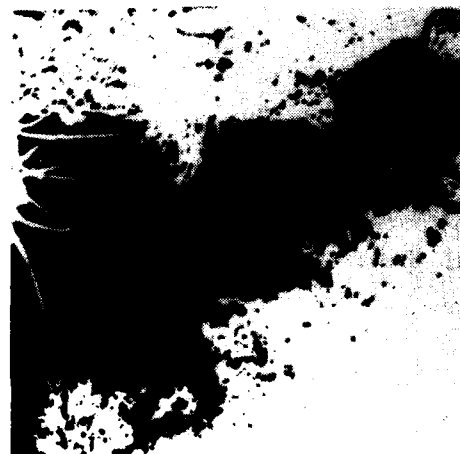


Fig. E6. Ice exposed under the grass.



Fig. E7. Plant roots exposed during ice melting.



Fig. E8. The surface collapses during ice melting.

#### Ground Ice and Permafrost

Ground ice is fully developed in the continuous permafrost region. Layers of pure ground ice often can be found on shady slopes and valleys with wet and marshy ground surface. Ground ice can be up to 20 m thick. In the continuous permafrost region, ground ice layers have been found at Mangui, Dalaigou, Daerbuer and Yitulihe. Figures E5 through E8 show ground features of the fields with ground ice buried beneath, the growth of ground ice, and the collapse of the land surface caused by melting of the ice layer.

The Mangui ground ice layer is comparatively shallow and is immediately beneath the peat layer. Its maximum thickness is 1.5-2.0 m. The temperature of the ice layer has a distribution that follows the rules of the geothermal distribution of the local permafrost (Table E4).

The geophysical phenomena of permafrost are well developed in all the permafrost regions. There are often river icings, spring icings, and groundwater icings. At 124 places investigated on the railways in the region, icings and icing mounds have deformed the railway track and affected transportation. On the Yalin Line alone there are more than 50 such sites. Figures E9 and E10 show the characteristics of the icings and the icing mounds. The phenomena of cold and wind-blown effects, thaw lakes, and thaw-freezing mud torrents are also wide-spread (see Figs. E11 and E12).

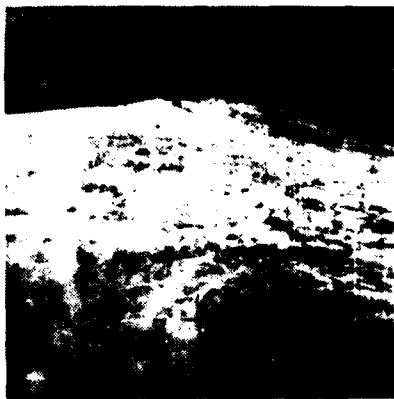


Fig. E9. Icings along railways.



Fig. E10. The mouth of a  
spring on top of a spring  
city.

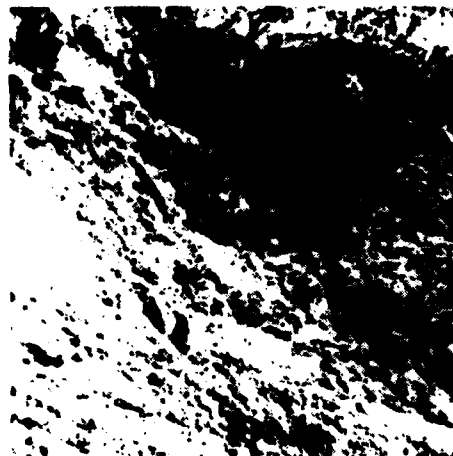


Fig. E11. Mud flow formed along the thaw front of a boundary slope.



Fig. E12. A thaw lake along the railway.

Table E4. Statistical upper limit variation of various soils under different covers.

| Type of soil                     |               | Heat preservation and upper limit (m) |           |           |
|----------------------------------|---------------|---------------------------------------|-----------|-----------|
|                                  |               | Excellent                             | Average   | Poor      |
| 0.0 ~ 0.1 m under peat and grass | sandy clay    | 0.7 ~ 1.2                             | 1.3 ~ 1.7 | 1.8 ~ 2.2 |
|                                  | gravel & sand | -                                     | -         | -         |
|                                  | gravel & soil | 1.1 ~ 2.0                             | -         | 2.1 ~ 3.5 |
|                                  | pebble & soil | 2.0 ~ 2.8                             | 2.9 ~ 3.5 | 3.6 ~ 4.3 |
| 0.2 ~ 0.4 m under peat           | sandy clay    | 0.5 ~ 1.1                             | 1.2 ~ 1.6 | 1.7 ~ 2.0 |
|                                  | gravel & sand | 0.6 ~ 1.1                             | 1.2 ~ 1.6 | 1.7 ~ 2.1 |
|                                  | gravel & soil | 0.9 ~ 1.7                             | -         | 1.8 ~ 3.0 |
|                                  | pebble & soil | 1.0 ~ 1.6                             | 1.7 ~ 2.3 | 2.4 ~ 3.3 |
| 0.5 ~ 0.7 m under peat           | sandy clay    | 0.4 ~ 1.0                             | 1.1 ~ 1.2 | 1.3 ~ 1.5 |
|                                  | gravel & sand | 0.4 ~ 1.0                             | 1.1 ~ 1.2 | 1.3 ~ 1.4 |
|                                  | gravel & soil | -                                     | -         | -         |
|                                  | pebble & soil | 0.4 ~ 1.1                             | 1.2 ~ 1.7 | 1.8 ~ 2.2 |

#### ROADBEDS IN THE PERMAFROST REGION

The upper limit of the permafrost at the base of the roadbed often recedes. This produces roadbed-bottom thaw and causes settlement of the roadbed itself. This constitutes the main problem for railway roadbeds in the Da Hinggan Ling permafrost region. The problem exists widely on the Yalin Railway and the Nunlin Railway, especially on the section between Jinlin and Jinhe stations on the Yalin Railway.

This section of the Yalin Railway is located on the permafrost region in the interior of the Da Hinggan Ling, at 51°12'N and 860 m above sea level. The railway passes through the low slope area in front of the mountains on low earth-filled embankments. The land surface here has a 0.5°-3° slope. The natural land surface is covered with tatao grass and azalea bushes. The peat layer is 0.4-1.0 m thick. All year round, saturated groundwater flows freely. A great quantity of water gathers at

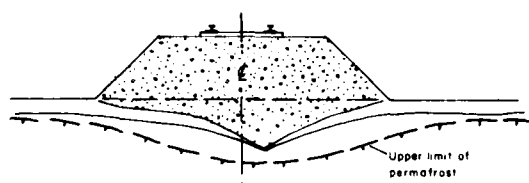


Fig. E13. The thaw bulb under a foundation.

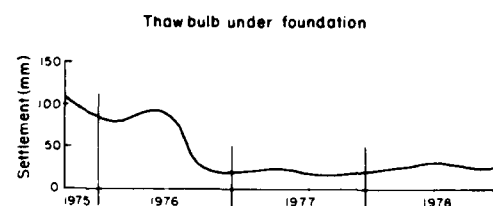


Fig. E14. Curve showing the settlement of a roadbed cross-section

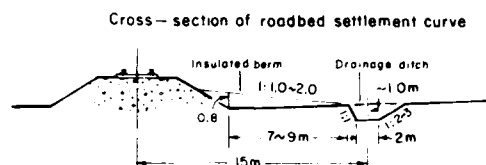


Fig. E15. Standard design cross-section of the general drainage ditch and insulation berm.

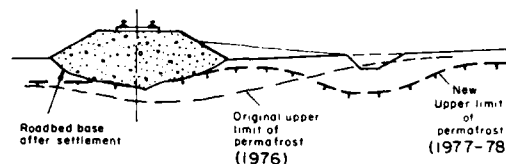


Fig. E16. The pattern of change of the permafrost upper limit under a foundation.

the foot of the roadbed slope and penetrates to the roadbed bottom. Under the peat layer there is mainly a mixed layer of muddy sandy clay and ice. Water makes up more than 40% of this layer. The upper limit of the permafrost is at a depth of approximately 0.9 m.

Since this roadbed section was used, it has been continuously settling at an annual rate of 0.1-0.13 m. The general remedial repair project for the experimental roadbed section is to construct a thermal insulated beam (in lieu of reverse-water slope) and a large 15 m cross-section drainage ditch nearby. These measures will, it is hoped, restore the temperature of the roadbed base and the position of the upper limit of the permafrost. Figures E13-E16 show the cross-section of the roadbed under examination, cross-section before and after the repair, the general project standard cross-section of the thermal insulated berm and the drainage ditch, as well as the changing conditions of the upper limit of the permafrost under the roadbed. Figure E17 shows the remedial constructions.



Fig. E17. An insulated berm (a) and a drainage ditch (b).



Fig. E18. Fallen rock from a boundary slope formed (caused?) by cold and wind-blown effects.

Under the force of gravity, water gathered at the roadbed sides tends to penetrate along the top of the permafrost toward the opposite side. This is another factor that causes the settlement of the roadbed. Because of the cold, freezing temperature, and wind, the rocks of the boundary slope fall and often block the railway. During the thaw seasons, the boundary slope, under the force of gravity, slides along the thaw front and produces mud flow; failure and creep of the boundary slope is also frequent (Figs. E18 and E19).

Icings and icing mounds also threaten the stability of the roadbeds in permafrost areas. At 124 places in the area investigated, icings and icing mounds have damaged the railways.

The damage to the railways caused by icings and icing mounds include:

- 1) ice on the railways, sometimes to the point that the safety of transportation is threatened. At 140 km from the starting point of the I-Jia Railway, at 311 km from the starting point of the Bai-A Railway, at 52 km from the starting point of the Bolin Railway, and at 222 km from the starting point of the Nunlin Railway, icings have interrupted transportation on the railways.
- 2) Freeze-damage of roadbeds caused by icings and icing mounds is far greater in scale than that caused by ordinary freeze damage. In the case of icing mounds and icings, freeze-damage is often over 50 mm, some over 200 mm.
- 3) Icings and icing mounds often cause fissures, looseness, softness, settlement, and failure of the roadbeds. A large labor force has

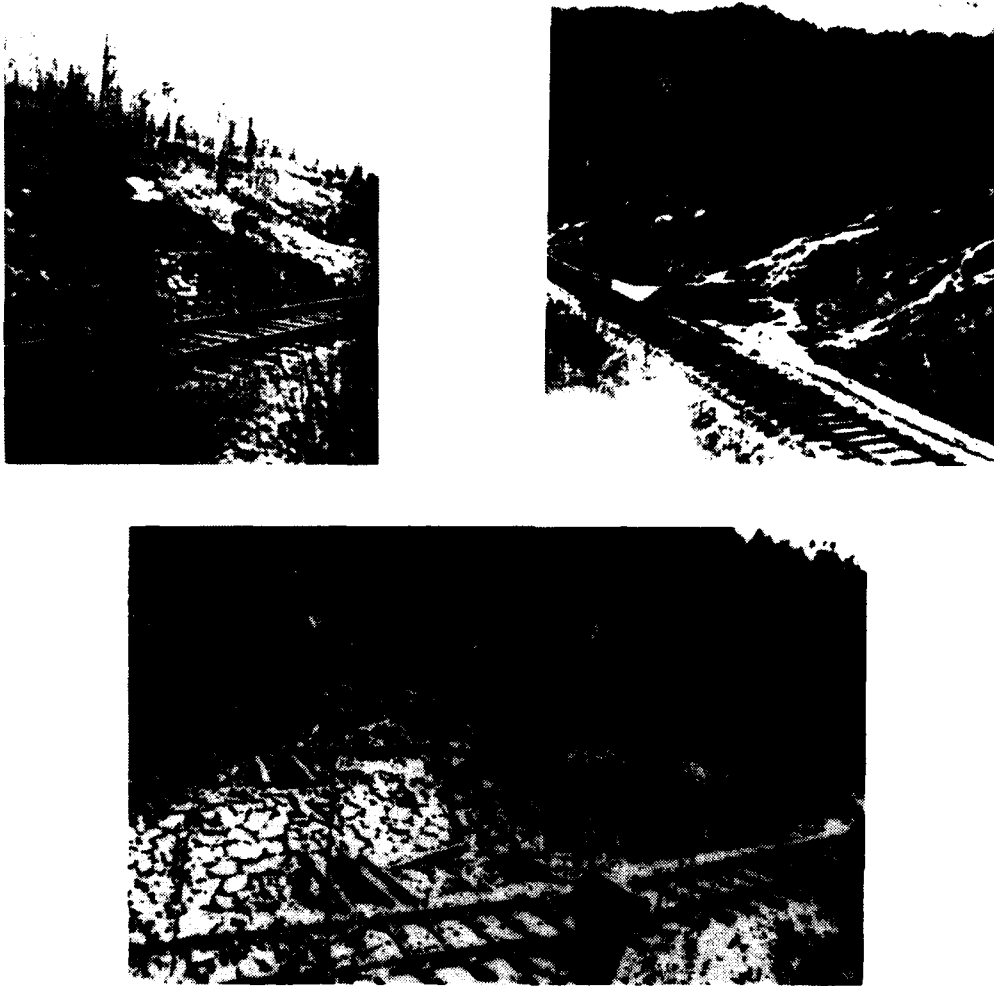


Fig. E19. Creep collapse of the boundary slope.

to be used to remove the ice and maintain operation of the railways when icings and icing mounds form. Over the years, 5000 work days of labor have been used to remove the ice at 8 important icing spots on the Genhe construction section and 6400 work days of labor have been used to remove ice at 10 important icing spots on the Tahe construction section.

In the past, the freeze-ditch, ice ditch, cut-water-wall, and ice wall methods have often been used to prevent icing mounds (Fig. E20 and E21). In recent years, insulated ditches have been widely adopted (Fig. E22 and E23). This kind of ditch gathers groundwater and disposes of it outside of the railway construction area. This method lowers the level of groundwater and also drains the groundwater. When groundwater sources have been eliminated, icings and icing mounds cannot form.



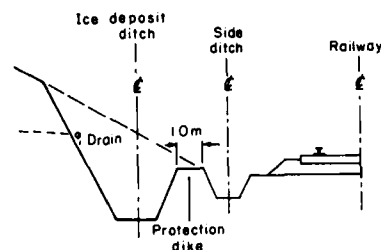


Fig. E20. Design cross-section of the ice deposit ditch within the boundary.

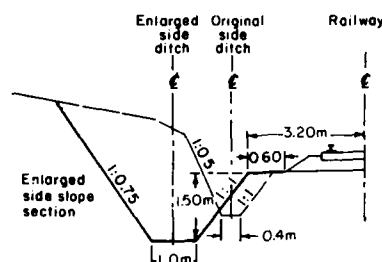


Fig. E21. Design cross-section of the enlarged side ditch.

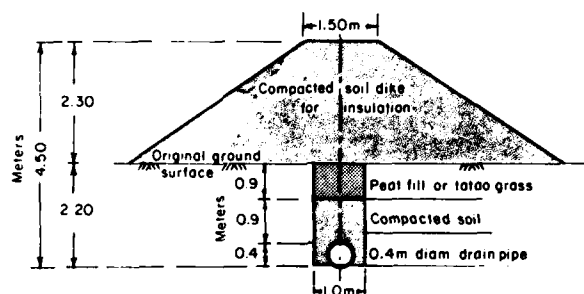
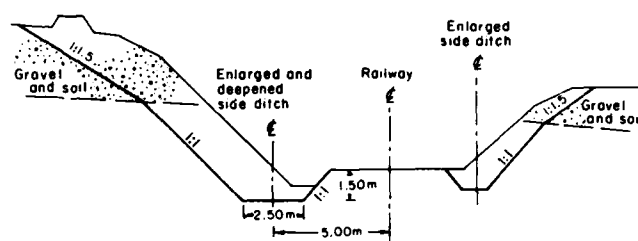


Fig. E22. Design cross-section of the insulated ditch.



Fig. E23. Insulated room of the insulated ditch.

## BRIDGE AND TUNNEL CONSTRUCTION IN THE PERMAFROST REGION

### Bridges

In the frost region, bridge problems caused by annual freeze and thaw are most apparent in the remaining wooden bridges on the Yalin Railway. The foundations of the wooden piers settle up to 410 mm and heave up to 600 mm. The wooden piers tend to incline and the ties are displaced off center with the tracks in a perpendicular direction.

Even the concrete abutments of bridges often settle and incline (perpendicularly or sideways) along the railways, in the permafrost regions (Region I) due to a nonsymmetry of the thawing areas formed by rivers, and in Regions II and III due to the unevenness of the island-shaped permafrost at the bridges and the crossings. The case of the bridge 146 km from the starting point of the Yalin Railway is typical. This bridge is located on the upper reaches of the Hailar River and is 40 m long and 5.12 m high. Its broad concrete foundation is buried 4 m underground. Because of the degradation of the 11-15 m permafrost under the foundations of the bridge abutment at Yakeshi, the abutment inclined backward and caused the movable support to shift 98 mm off center perpendicular, enlarging the gap to the bridge up to 300 mm (Figs. E24-E26).



Fig. E24. The gap between the ends of the beam increased because of the tilt of the abutment.



Fig. E25. The support deviated from the center position because of the tilt of the abutment.



Fig. E26. Tilt of the support of the timber raft.

Wooden structure bridges are repaired by emplacing auxiliary wooden piers and auxiliary piles, thus eliminating the spots where the structure is too far off-center and the wooden piers are over-inclined. Pile foundations are installed to protect the skirts of the settling timber foundations and to strengthen the foundation bearing capacity. A protective layer of charcoal dregs is provided for the foundation (abutment?) face of frost-damaged bridges to reduce the depth of annual freeze and to eliminate heave effects.

### Tunnels

Most of the railway tunnels in the region have drainage tunnels to drain groundwater (Figs. E27 and E28). However, due to the low temperature of the rock, ice collects and blocks the drainage tunnels and thus blocks the groundwater in the peripheral rocks of the tunnels, producing over-pressure to form large-scale flooding and freezing in the railway tunnels. The ice formed covers the railways and disrupts transportation. A breakthrough in recent years is the ventilation-melting method used on the ice formed in the drainage tunnels. This method utilizes a forced ventilation system. The heat supply in the natural air is used to melt the ice and allow drainage of the water in the drainage tunnels. During the ventilation process, the temperature in the drainage tunnels can rise to  $10^{\circ}$  or  $15^{\circ}\text{C}$  at the inflow end. The average amount of heat exchange exerted by the air drift to ice can reach 440,000 kcal/hr. Ventilation for 185 hr can melt 400 cm of ice within the tunnel.



Fig. E27. Settlement of a culvert.

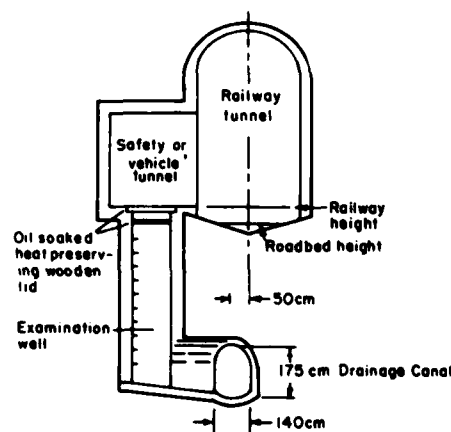


Fig. E28. Positioning of the drainage tunnel.

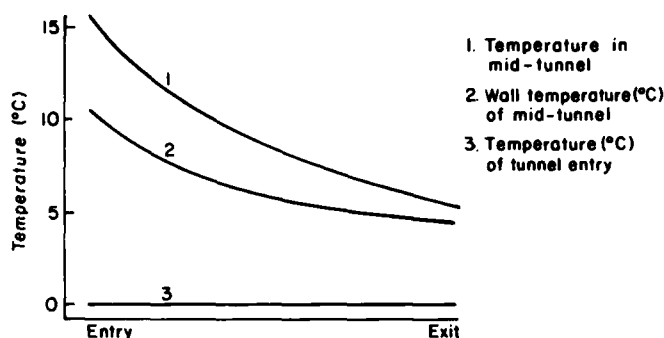


Fig. E29. Temperature change within an air-circulating tunnel.

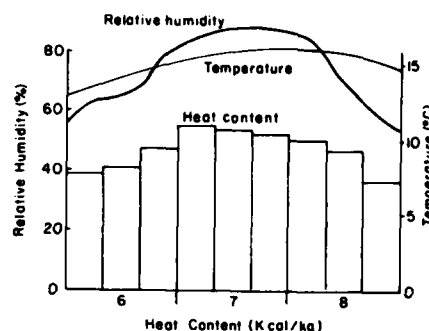


Fig. E30. Heat content, temperature, and humidity changes of local air.

The effect of the heat exchange between air drift and ice surface is determined by the heat content and heat discharge of the air drift. It is important that there be a big difference between the temperature of the air drift and the temperature of the ice surface and that there be a large heat exchange area. The ventilation ice-melting facilities should be constructed in the comparatively warm months of July and August. At this time of year, the average heat exchange index of the air drift can reach 33-35 kcal/hr m<sup>2</sup> °C (Figs. E29 and E30).

#### River Ice

River ice flow loading on bridge buttresses (piers?) is a major threat to bridges during spring thaw. Drifting ice pressure experiments have been conducted to study the physical process of the head-on collision between ice and the bridge buttress and to collect all the physical and quantitative data needed in the calculation formula. Field preparatory work should be accomplished 10 to 15 days before the ice on the river breaks. A 3 m wide and 20 m long ice trough is then made on the surface of the bridge buttress facing the stream flow (Fig. E31). A pressure transmitter is put on the buttress and one vibration recorder is placed every 3 m along the full height of the bridge buttress. The ice pressure curve and the bridge buttress vibration curve show the results of the experiments.

The following equation for the pressure of flowing water is based on the principle of momentum:

$$P = V \sqrt{\frac{m_1 \left( \frac{m_1}{m_1 + m_2} - e_2^2 \right)}{a_1 + a_2}}$$

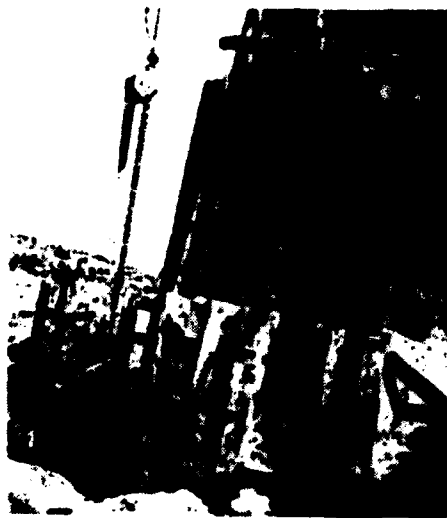


Fig. E31. Scenes from a drifting ice pressure experiment.

In the equation

$V$  = the flowing velocity of the ice flow, m/s

$m_1$  = the mass of the ice flow (engineering mass unit)

$m_2$  = the mass of the bridge buttress (engineering mass unit)

$e_2$  = restore index after the collision of the ice flow

$a_1$  = distortion index of the bridge buttress

$a_2$  = distortion index of the bridge buttress vibration

## BUILDING CONSTRUCTION IN THE PERMAFROST REGION

### Permafrost Damage

The houses along the railways in the permafrost region, because of the direction and positions of the railways, are mostly built on step land and low slopes in front of the mountains. These are the places where the permafrost is fully developed. The foundations of the buildings at these places, under the influence of human activities such as construction, industrial production, and forest and farm development, undergo rapid changes. In permafrost Region I, the upper limit of the permafrost can recede up to 0.6 to 1.0 m. The depth to the zero annual average geothermal change (zero amplitude depth) increases 2-4 m. Ground temperature at 10 m can increase by 0.4-0.6°C. In permafrost regions II and III, the degradation phenomena of the permafrost is even more pronounced. All these cause changes in the thermal situations of the permafrost region building foundations and thus affect the stability of the houses. Figure E32 shows typical damages to buildings within the region. Analysis of the results of investigation concerning various types of houses at different stations on the Yalin Railways between Yitulihe and Mangui shows that the damage rate exceeds 60% (see Table E5 and E6). The tables include only houses built on permafrost foundations. Houses built on rock foundations or partially thawing foundations are not included.

In addition, because of bad choices of building location, buildings are often subjected to blizzards or are damaged by undesirable geological phenomena such as icings and icing mounds.

### Aboveground Foundations

The experiments and research done on the construction of aboveground foundations in the Mangui area have increased confidence in local permafrost constructions. Mangui was an area where buildings sustained a high



Fig. E32. Damaged buildings in the permafrost region.

Table E5.

| Number of<br>buildings<br>investigated | Intact | Slightly<br>damaged | Comparatively<br>seriously<br>damaged | Seriously<br>damaged | Note                          |
|--|--------|---------------------|---------------------------------------|----------------------|-------------------------------|
| 230                                    | 85     | 62                  | 48                                    | 35                   | All built<br>on<br>permafrost |
| 100%                                   | 36.9%  | 26.9%               | 20.8%                                 | 15.4%                |                               |

Table E6.

| Depth of<br>buried<br>foundation<br>(m) | Number<br>of<br>buildings | Intact | Slightly<br>damaged | More<br>seriously<br>damaged | Seriously<br>damaged | Note                          |
|---|---------------------------|--------|---------------------|------------------------------|----------------------|-------------------------------|
| 1.0 - 2.0                               | 44                        |        | 13                  | 11                           | 20                   | All built<br>on<br>permafrost |
| 2.1 - 2.8                               | 67                        | 18     | 25                  | 19                           | 5                    |                               |
| 2.9 - 4.9                               | 26                        | 6      | 11                  | 9                            |                      |                               |

damage rate: 70% or more of the houses have rather serious cracks. The soils in this area belong to the strong heave and strong thaw settlement type. In the past, buildings on ordinary foundations, after having been used for eight years, would show the following phenomena. The thaw bulb formed in the permafrost would have a depth of 5-7 m (and a lateral extent of 5-6.5 m), and the annual heave and settlement of the ground could cause the building foundation to have a rise-fall of 70-130 m.

In recent years, permafrost foundation construction has emphasized protecting the permafrost from thaw. Aboveground foundations have been used, on a trial basis, for various types of buildings. These foundations adjust well to permafrost conditions and can be used for different kinds of soils where the annual average ground temperature is under  $-1.5^{\circ}\text{C}$ . Figures E33-E35 show a shallowly buried, mound-style aboveground house foundation. On the ground surface is a 1.0 m thick compacted peat thermal layer. Within the boundary of the building, the upper limit of the permafrost rises about 0.4 m.

Pile style aboveground building foundations can also be used for building in areas with ground ice, provided that the vegetation (peat) protective layer on the ground surface is intact, that there is enough distance (according to the requirements of thermodynamics) between the ice



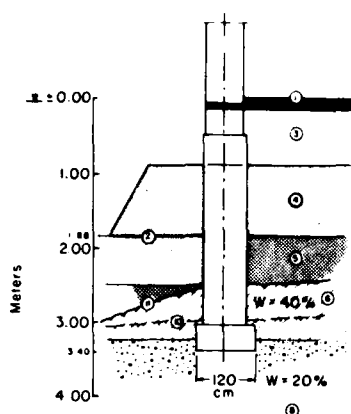


Fig. E33. Aboveground building foundation built on stones/slab paved mound in the Mangui area. 1) ground surface building rooms; 2) natural ground surface; 3) ventilation space; 4) layer filled with compacted soil; 5) peat; 6) clayey soil; 7) sandy soil; 8) sandy gravels; 9) ice layer; 10) upper limit of natural permafrost; 11) man-made upper limit of frozen soil; 12) designed thaw margin.

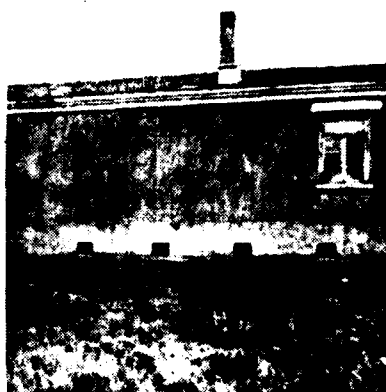


Fig. E34. Aboveground house built on a low mound of filled earth.



Fig. E35. Aboveground house built on wide stone slab foundation.

layer and the upper limit of the permafrost, and that the temperature of the ice layer equals the temperature of the permafrost. Figures E36-E38 show the foundations of a house built on the ground with a thick ground ice layer. Piles were inserted into drilled holes, reaching as deep as 5.2 m in the permafrost. The bearing capacity of a single pile is  $N = 31,000 \text{ N}$ . The ground temperature is  $-1.7$  to  $-2.0^\circ\text{C}$ . The upper limit of the permafrost shows a slight elevation within the boundary of the building. The temperature of the ice layer is stable.

A total of  $2220 \text{ m}^2$  of experimental building foundations and buildings on them have been so far constructed in the Mangui area. The oldest are now 10 years old. They still have stable foundations and are in good shape. At present, pile style aboveground building foundations have been used for various buildings in Jinlin, Mordaga, and Yitulihe.

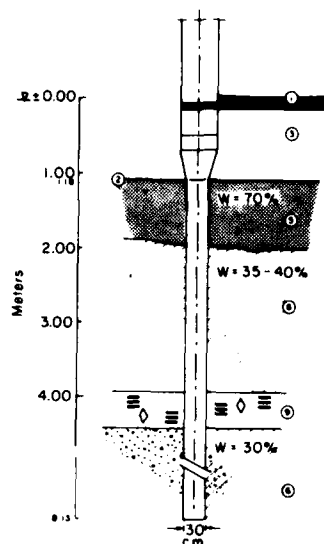


Fig. E36. Aboveground building foundation built on reinforced concrete piles in the Mangui area: 1) ground surface building rooms; 2) natural ground surface; 3) ventilation space; 4) layer filled with compacted soil; 5) peat; 6) clayey soil; 7) sandy soil; 8) sandy gravels; 9) ice layer; 10) upper limit of natural permafrost; 11) man-made upper limit of frozen soil; 12) designed thaw margin.

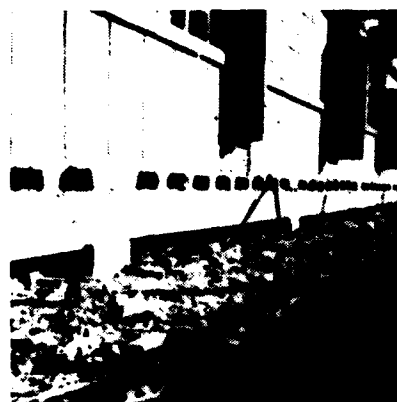


Fig. E37. Pile foundation, aboveground building under construction.



Fig. E38. Pile foundation, aboveground building built on ground with a thick underground ice layer.

Theoretical studies on the thawing of permafrost have described the situations and changing process of the peripheral region of the ground thaw and provided the calculating procedures and formula for the thaw depth of ground under the insulated buildings. The thaw depth for the ground under the middle part of the building is obtained from

$$H_M = K \cdot H_G \quad (m)$$

In the formula,  $H_G$  is thaw depth of the ground under the influence of factors like indoor floor (floor heat resistivity) and underground heat sources:

$$H_G = a \cdot \operatorname{ctg} \left[ \frac{\pi}{2} \cdot \frac{(F+GH_S) \cdot (H_S+S)}{(F-f_T) \cdot (H_S+S) + S f_T} \right]$$

and  $K$  is the index for the influence of the ratio of length of the building to the width of the building on the thaw depth of the central part.

The premises for the above equation are: 1) The uniformity of the soil quality. It is necessary to average the non-uniform soil layer by seeking out the weighted average for the depth and area. 2) The imitative (predicted?) stability of the thermal field. The premises for the linearity problem have already been recognized. Concerning the two-dimensional non-linear Stephan's formula, because of the existence of the continuously expanding thaw front and the diffusion of heat, this basic premise is even more strongly supported. According to the above premises, the potential equation is used in lieu of the heat transmission equation, i.e. for each given time, temperature distribution is used as the function of spatial variant to satisfy the potential equation.

Data for different temperatures, buildings, and ground factors are fed into a computer and later the nomogram for finding  $H_M$  can be drawn (Fig. E39). Given  $F$  = average outdoor annual temperature;  $G$  = geothermal gradient value of the ground layer;  $S$  = thickness of the suitable quality layer of the insulation layer a half-access distance from the building;  $f_T$  = data for the indoor annual average temperature, then  $H_M$  can be found in the nomogram.

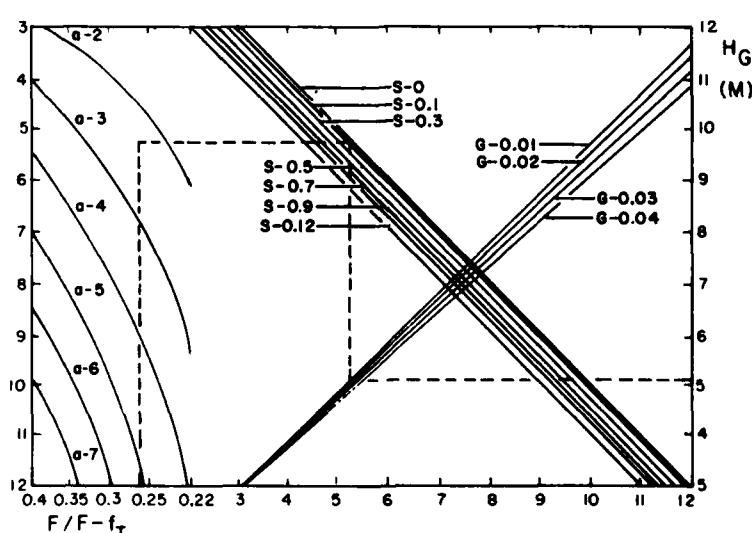


Fig. E39. Nomogram for finding  $H_M$ .

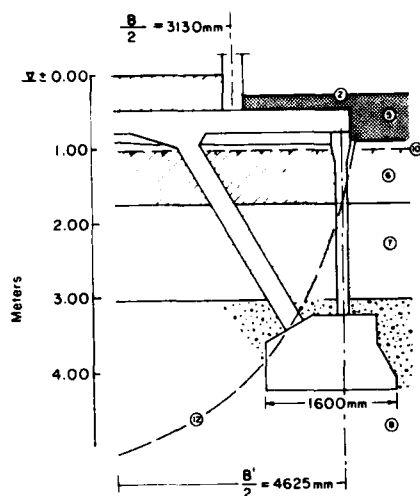


Fig. E40. Truss foundation in the Yitulihe area. 1) ground surface building rooms; 2) natural ground surface; 3) ventilation space; 4) layer filled with compacted soil; 5) peat; 6) clayey soil; 7) sandy soil; 8) sandy gravels; 9) ice layer; 10) upper limit of natural permafrost; 11) man-made upper limit of frozen soil; 12) designed thaw margin.



Fig. E41. House built on truss-style foundation at Yitulihe.



Fig. E42. Mangui railway station, which has a ventilated basement.

The truss foundation in Figures E40 and E41 is an experimental house foundation built in the Yitulihe area in recent years. It was designed according to the ground thaw theory. When the boundary of the ground thaw area is given, the bearing capacity of the crossing truss foundation ground is, according to the frost ground value,  $R = 6.5$  (million?) pa. ("million?" may be factor of 10,000 or hundred-hundred).

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